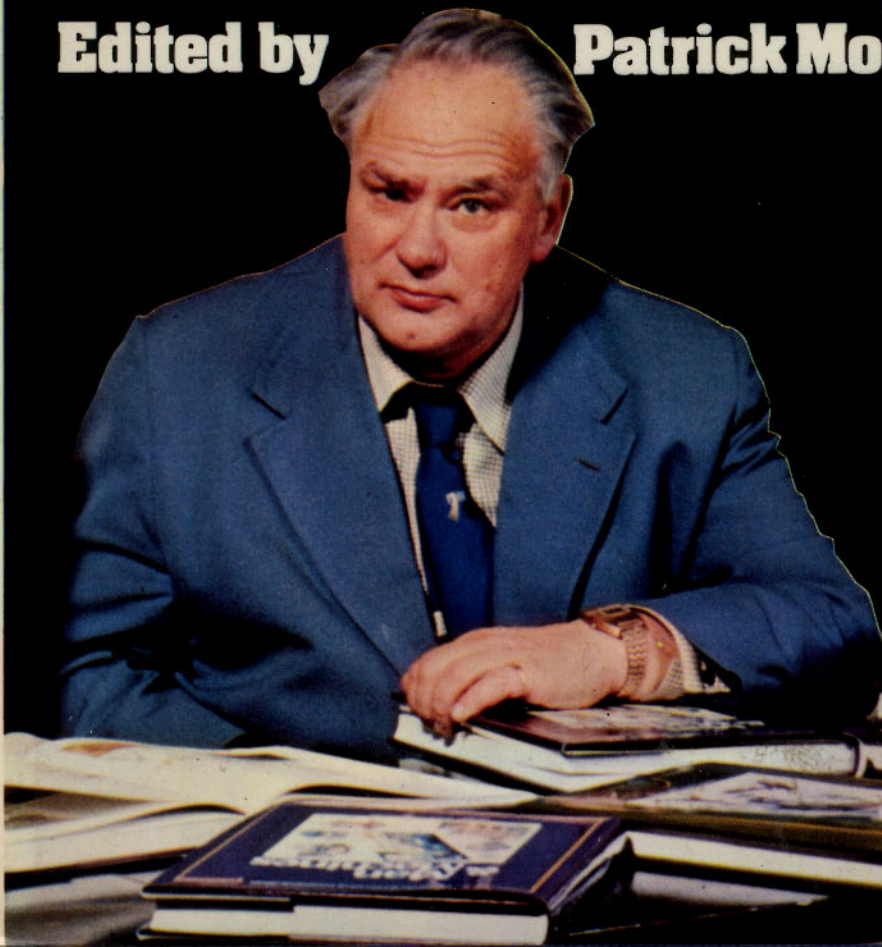
1978 Yearbook of Astronomy

Edited by Patrick Moore



1978 YEARBOOK OF ASTRONOMY PATRICK MOORE

Sidgwick & Jackson

1978 Yearbook of Astronomy

£4.50
In UK only

There is a major change in this edition. The Editor, writing with the authority of personal knowledge, says: "Astronomy is a truly international subject; and now that the **Yearbooks** are read and used all over the world, it is time to include southern star maps. These have been prepared by Dr. Porter, whose monthly notes are now equally relevant to both hemispheres." Thus observers will be able to know what is happening on the other side even though they can't see.

The usual essential information on planets, eclipses, comets, and meteors is included, while the lists of double stars, variables, clusters, and nebulae have been extended.

The article section is as varied as ever, with illustrations and diagrams as applicable. Our contributors include old and new friends, as the following list shows:

Observatory Fitments	**F. R. Spry**
The Earth and the Moon	**R. Maddison**
The Zodiacal Light	**J. C. D. Marsh**
Craters on Mercury and Mars	**S. Miyamoto**
The Atmosphere of Mars: Past, Present and Future	**G. E. Hunt**
Neutron Stars	**J. Bell Burnell**
Extragalactic Nomenclature – A Simple Guide	**S. Mitton**
What's New in the Local Group	**Heather Couper**
Interstellar and Intergalactic Matter	**I. Nicolson**
Recent Events in Astronomy	**Patrick Moore**

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PATRICK MOORE

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Editor's Foreword

Those who have read the *Yearbooks* over the past fifteen years will notice a major change in this new version. Ever since 1962, when the series began, the main emphasis has been upon the Northern Hemisphere, and only northern monthly charts have been included. However, astronomy is a truly international subject; and now that the *Yearbooks* are read and used all over the world, it is time to include southern star-maps. These have been prepared by Dr Porter, whose monthly notes are now equally relevant to both hemispheres. The lists of double stars, variables, clusters and nebulæ have also been extended.

As usual, the article section includes 'something for everybody', ranging from observatory hints to the movements of the Moon, the local group of galaxies, and neutron stars—the latter written by Dr Jocelyn Bell Burnell, who was the first to identify these remarkable objects now known as pulsars. There is also an important review article, by Dr Garry Hunt, concerning the new findings about the atmosphere of Mars. This kind of article would have seemed very futuristic in 1962, before the first successful Mars probe had been launched.

PATRICK MOORE

Selsey, 1977

Preface

New readers will find that all the information in this *Yearbook* is given in diagrammatic or descriptive form; the positions of the planets may easily be found on the specially designed star charts, while the monthly notes describe the movements of the planets and give details of other astronomical phenomena visible in both the northern and southern hemispheres. Two sets of star charts are provided. The **Northern Charts** (pp. 16 to 41) are designed for use in latitude 52 degrees north, but may be used without alteration throughout the British Isles, and (except in the case of eclipses and occultations) in other countries of similar north latitude. The **Southern Charts** (pp. 42 to 67) are drawn for latitude 35 degrees south, and are suitable for use in South Africa, Australia and New Zealand, and other stations in approximately the same south latitude. The reader who needs more detailed information will find *Norton's Star Atlas* (Gall and Inglis) an invaluable guide, while more precise positions of the planets and their satellites, together with predictions of occultations, meteor showers, and periodic comets may be found in the *Handbook* of the British Astronomical Association. A somewhat similar publication is the *Observer's Handbook* of the Royal Astronomical Society of Canada, and readers will also find details of forthcoming events given in the American *Sky and Telescope*. This monthly publication also produces a special occultation supplement giving predictions for the United States and Canada.

Important Note

The times given on the star charts and in the Monthly Notes are generally given as local times, using the 24-hour clock, the day beginning at midnight. The times of a few events (e.g.

eclipses) are given in Greenwich Mean Time (G.M.T.), which is related to local time by the formula

Local Mean Time = G.M.T. — west longitude.

In practice, small differences of longitude are ignored, and the observer will use local clock time, which will be the appropriate Standard (or Zone) Time. As the formula indicates, places in west longitude will have a Standard Time slow on G.M.T., while places in east longitude will have Standard Times fast on G.M.T. As examples we have:

Standard Time in			
New Zealand	G.M.T.	+	12 hours
Victoria; N.S.W.	G.M.T.	+	10 hours
Western Australia	G.M.T.	+	8 hours
South Africa	G.M.T.	+	2 hours
British Isles	G.M.T.		
Eastern S.T.	G.M.T.	−	5 hours
Central S.T.	G.M.T.	−	6 hours, etc.

If Summer Time is in use, the clocks will have been advanced by one hour, and this hour must be subtracted from the clock time to give Standard Time.

In Great Britain and N. Ireland, Summer Time will be in force in 1978 from 19 March 02^h until 22 October 02^h G.M.T.

PART ONE

Events of 1978

MONTHLY CHARTS and ASTRONOMICAL PHENOMENA

Notes on the Star Charts

The stars, together with the Sun, Moon and planets seem to be set on the surface of the celestial sphere, which appears to rotate about the Earth from east to west. Since it is impossible to represent a curved surface accurately on a plane, any kind of star map is bound to contain some form of distortion. But it is well known that the eye can endure some kinds of distortion better than others, and it is particularly true that the eye is most sensitive to deviations from the vertical and horizontal. For this reason the star charts given in this volume have been designed to give a true representation of vertical and horizontal lines, whatever may be the resulting distortion in the shape of a constellation figure. It will be found that the amount of distortion is, in general, quite small, and is only obvious in the case of large constellations such as Leo and Pegasus, when these appear at the top of the charts, and so are drawn out sideways.

The charts show all stars down to the fourth magnitude, together with a number of fainter stars which are necessary to define the shape of a constellation. There is no standard system for representing the outlines of the constellations, and triangles and other simple figures have been used to give outlines which are easy to follow with the naked eye. The names of the constellations are given, together with the proper names of the brighter stars. The apparent magnitudes of the stars are indicated roughly by using four different sizes of dots, the larger dots representing the bright stars.

The two sets of star charts are similar in design. At each opening there is a group of four charts which give a complete

coverage of the sky up to an altitude of 62½ degrees; there are twelve such groups to cover the entire year. In the **Northern Charts** (for 52 degrees north) the upper two charts show the southern sky, south being at the centre and east on the left. The coverage is from 10 degrees north of east (top left) to 10 degrees north of west (top right). The two lower charts show the northern sky from 10 degrees south of west (lower left) to 10 degrees south of east (lower right). There is thus an overlap east and west.

Conversely, in the **Southern Charts** (for 35 degrees south) the upper two charts show the northern sky, with north at the centre and east on the right. The two lower charts show the southern sky, with south at the centre and east on the left. The coverage and overlap is the same on both sets of charts.

Because the sidereal day is shorter than the solar day, the stars appear to rise and set about four minutes earlier each day, and this amounts to two hours in a month. Hence the twelve groups of charts in each set are sufficient to give the appearance of the sky throughout the day at intervals of two hours, or at the same time of night at monthly intervals throughout the year. The actual range of dates and times when the stars on the charts are visible is indicated at the top of each page. Each group is numbered in bold type, and the number to be used for any given month and time is summarised in the following table:

Local Time	18h	20h	22h	0h	2h	4h	6h
January	11	12	1	2	3	4	5
February	12	1	2	3	4	5	6
March	1	2	3	4	5	6	7
April	2	3	4	5	6	7	8
May	3	4	5	6	7	8	9
June	4	5	6	7	8	9	10
July	5	6	7	8	9	10	11
August	6	7	8	9	10	11	12
September	7	8	9	10	11	12	1
October	8	9	10	11	12	1	2
November	9	10	11	12	1	2	3
December	10	11	12	1	2	3	4

The charts are drawn to scale, the horizontal measurements, marked at every 10 degrees, giving the azimuths (or true bearings) measured from the north round through east (90 degrees), south (180 degrees), and west (270 degrees). The vertical measurements, similarly marked, give the altitudes of the stars up to 62½ degrees. Estimates of altitude and azimuth made from these charts will necessarily be mere approximations, since no observer will be exactly at the adopted latitude, or at the stated time, but they will serve for the identification of stars and planets.

The ecliptic is drawn as a broken line on which longitude is marked at every 10 degrees; the positions of the planets are then easily found by reference to the table on page 74. It will be noticed that on the southern charts the ecliptic may reach an altitude in excess of 62½ degrees on star charts 5 to 9. The continuation of the broken line will be found on the charts of overhead stars.

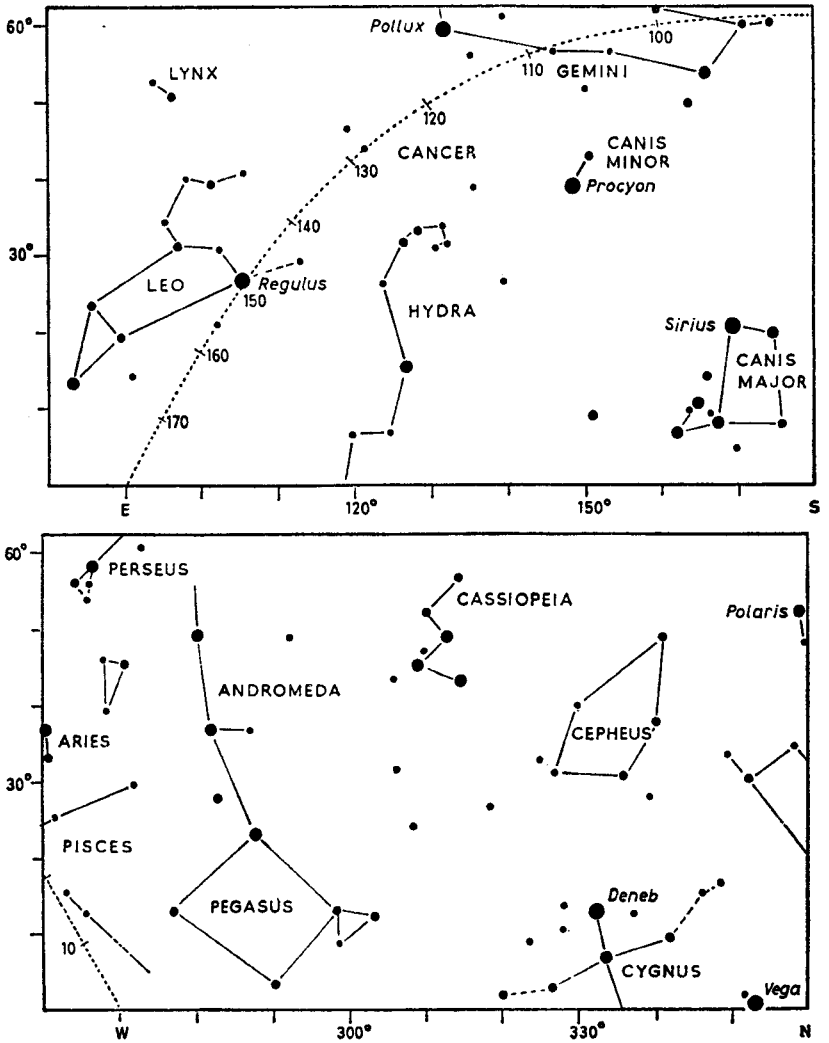
There is a curious illusion that stars at an altitude of 60 degrees or more are actually overhead, and the beginner may often feel that he is leaning over backwards in trying to see them. These overhead stars are given separately on the pages immediately following the main star charts. The entire year is covered at one opening, each of the four maps showing the overhead stars at times which correspond to those of three of the main star charts. The position of the zenith is indicated by a cross, and this cross marks the centre of a circle which is 35 degrees from the zenith; there is thus a small overlap with the main charts.

The broken line leading from the north (on the Northern Charts) or from the south (on the Southern Charts) is numbered to indicate the corresponding main chart. Thus on page 40 the N-S line numbered 6 is to be regarded as an extension of the centre (south) line of chart 6 on pages 26 and 27, and at the top of these pages are printed the dates and times which are appropriate. Similarly, on page 66, the S-N line numbered 10 connects with the north line of the upper charts on page 60.

The overhead stars are plotted as maps on a conical projection, and the scale is rather smaller than that of the main charts.

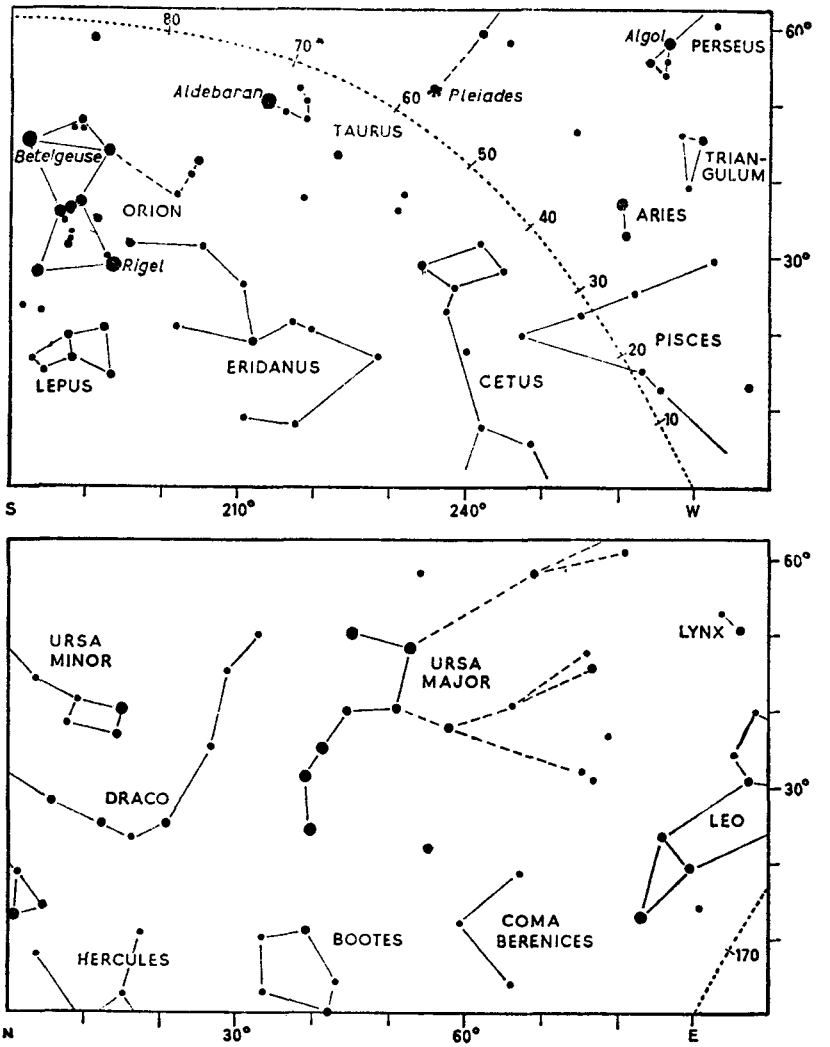
1L

October 6 at	5^h	October 21 at	4^h
November 6 at	3^h	November 21 at	2^h
December 6 at	1^h	December 21 at	midnight
January 6 at	23^h	January 21 at	22^h
February 6 at	21^h	February 21 at	20^h



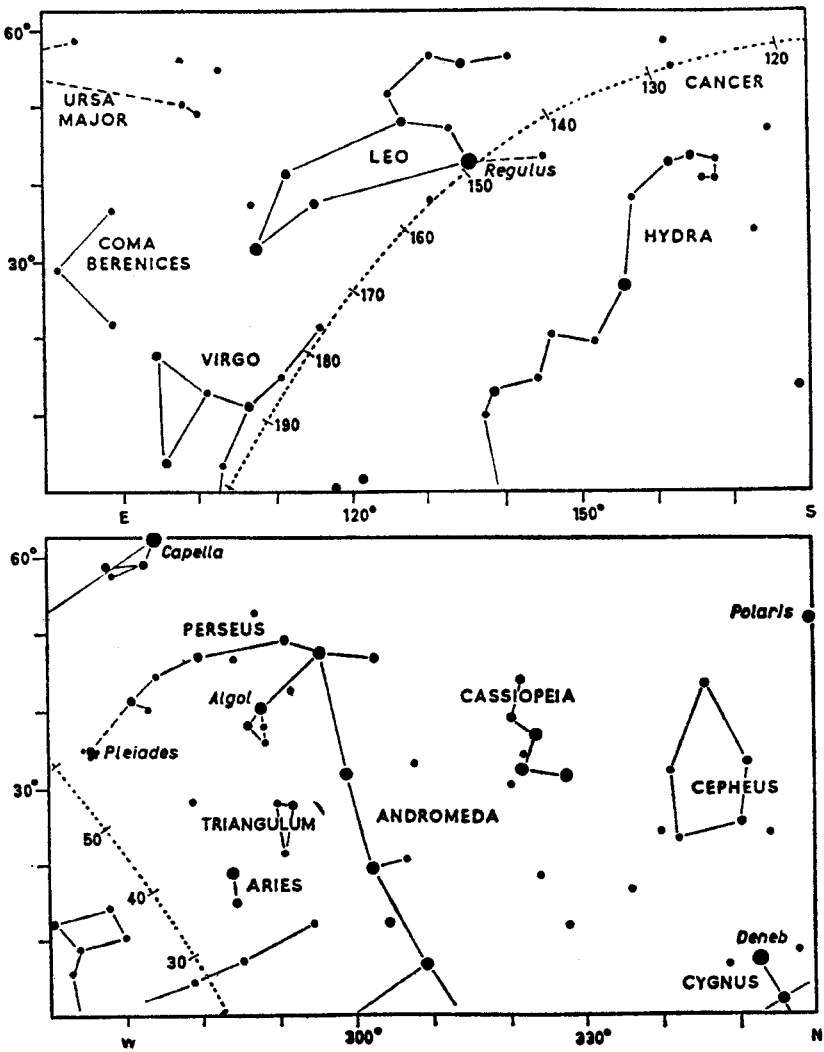
October 6 at	5^h	October 21 at	4^h
November 6 at	3^h	November 21 at	2^h
December 6 at	1^h	December 21 at	midnight
January 6 at	23^h	January 21 at	22^h
February 6 at	21^h	February 21 at	20^h

1R



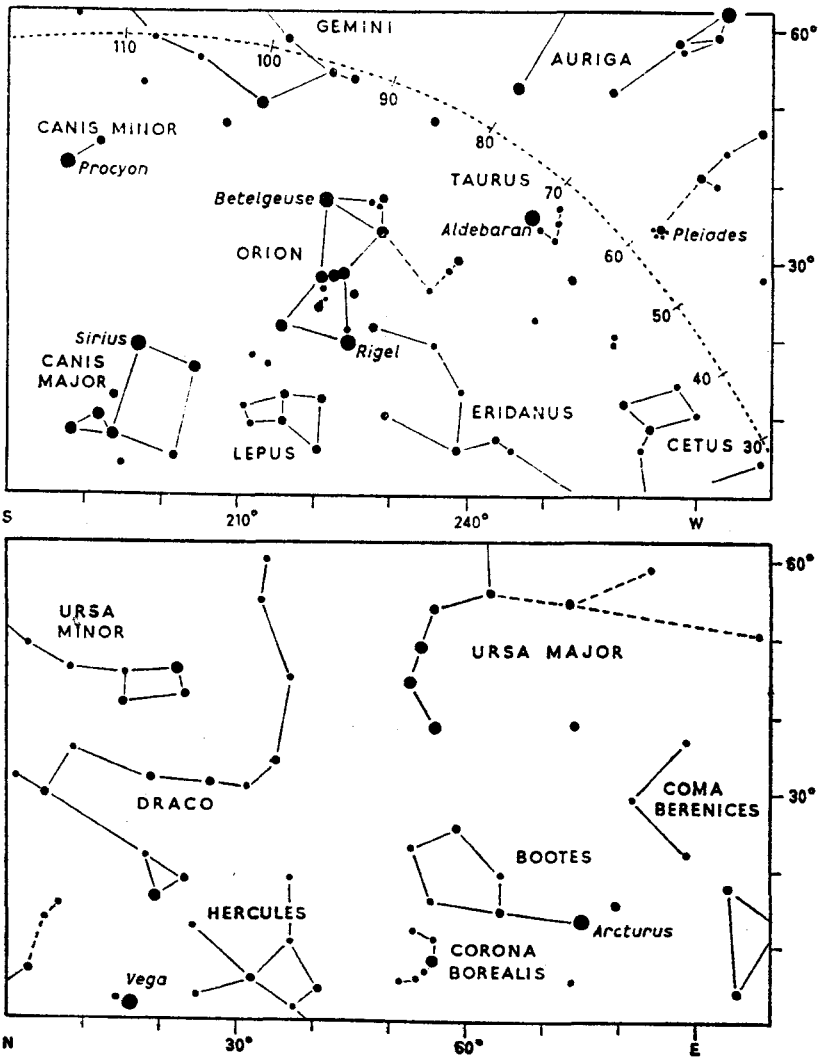
2L

November 6 at 5^h	November 21 at 4^h
December 6 at 3^h	December 21 at 2^h
January 6 at 1^h	January 21 at midnight
February 6 at 23^h	February 21 at 22^h
March 6 at 21^h	March 21 at 20^h



November 6 at	5^h	November 21 at	4^h
December 6 at	3^h	December 21 at	2^h
January 6 at	1^h	January 21 at	midnight
February 6 at	23^h	February 21 at	22^h
March 6 at	21^h	March 21 at	20^h

2R



3L

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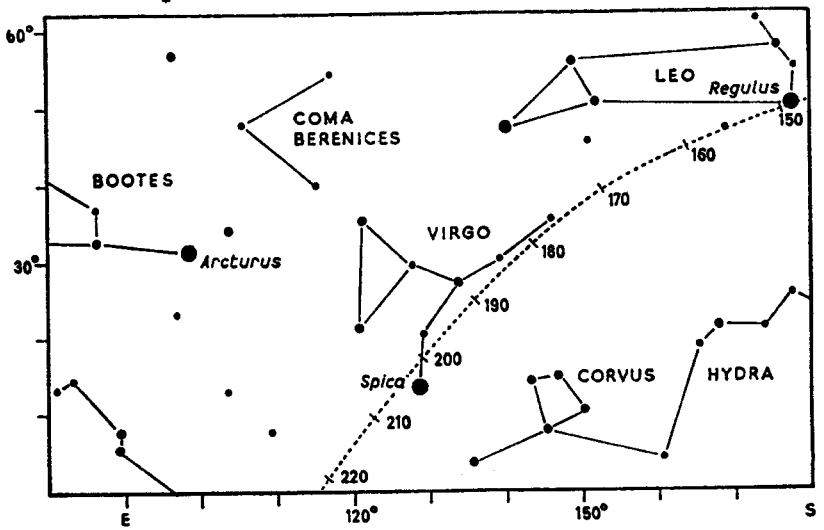
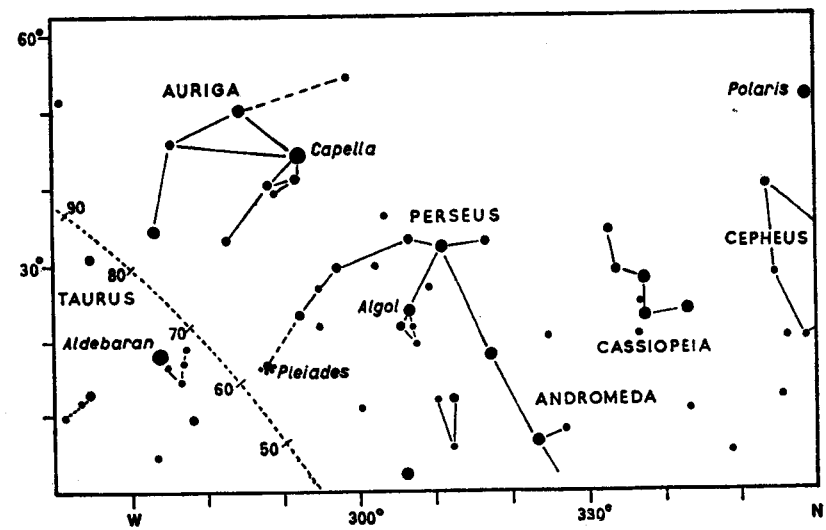
January 6 at	3^h	January 21 at	2^h
February 6 at	1^h	February 21 at	midnight
March 6 at	23^h	March 21 at	22^h
April 6 at	21^h	April 21 at	20^h





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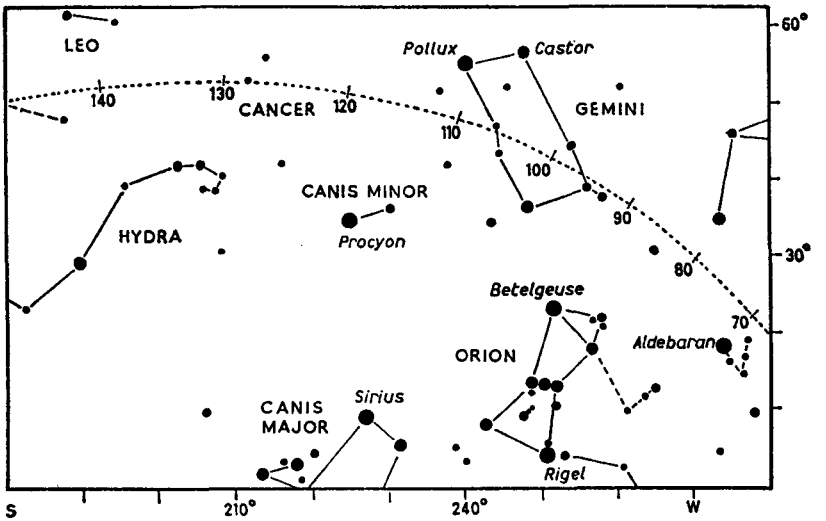
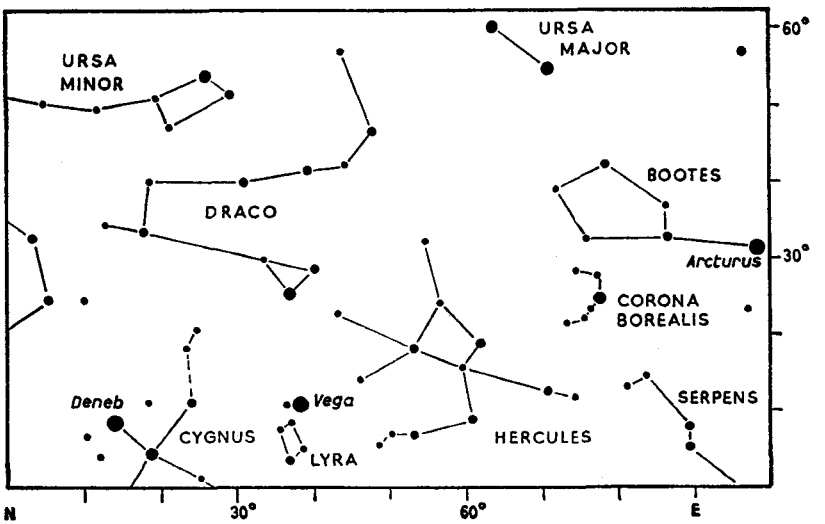
March 6 at	23^h	March 21 at	22^h
April 6 at	21^h	April 21 at	20^h

3R





4L

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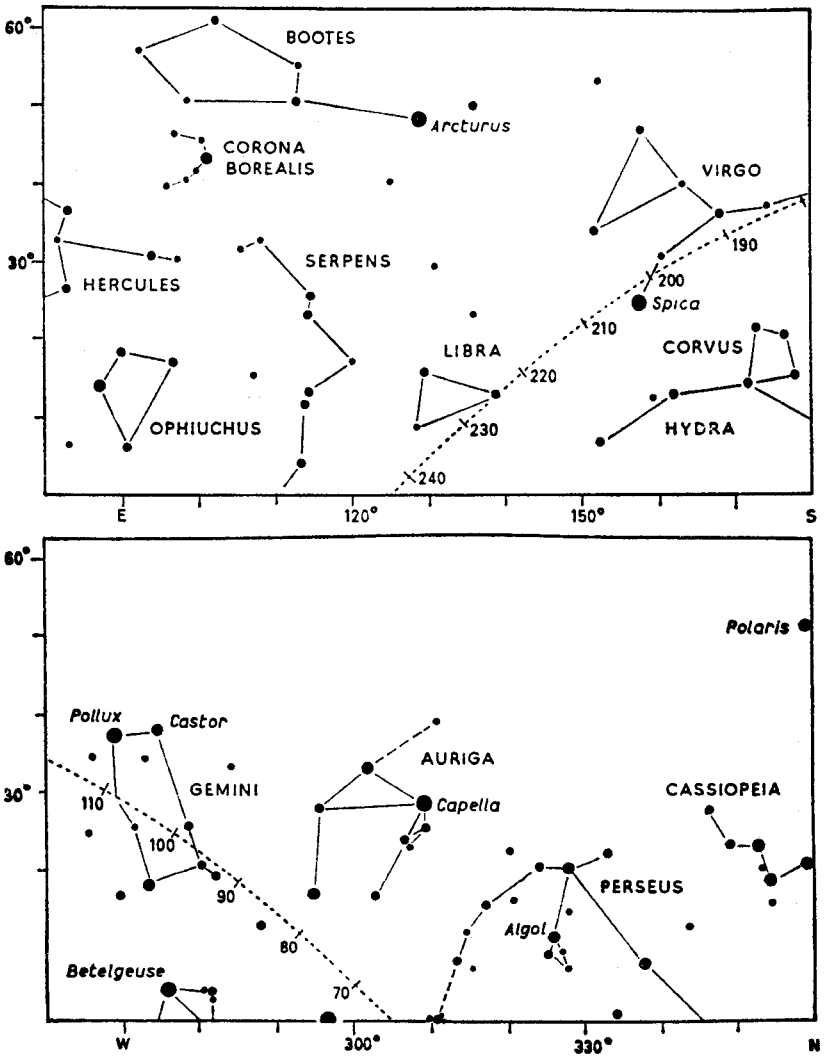
February 6 at	3^h	February 21 at	2^h
March 6 at	1^h	March 21 at	midnight
April 6 at	23^h	April 21 at	22^h
May 6 at	21^h	May 21 at	20^h



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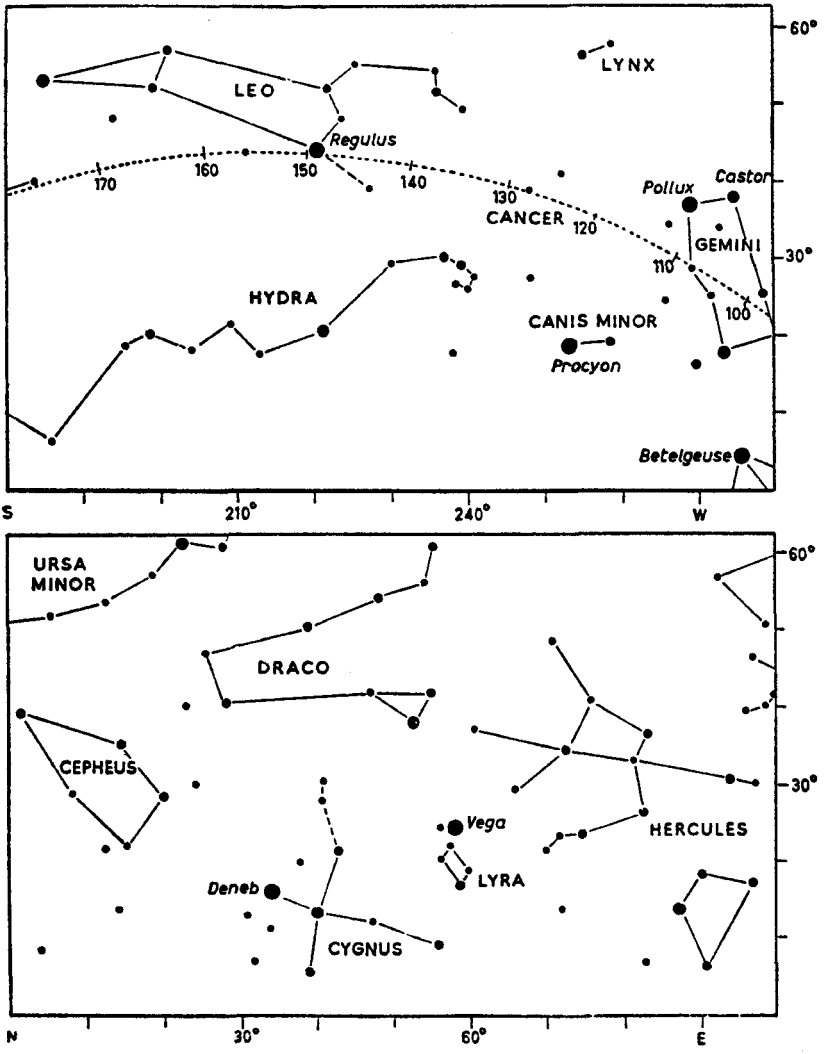
March 6 at	1^h	March 21 at	midnight
April 6 at	23^h	April 21 at	22^h
May 6 at	21^h	May 21 at	20^h

4R



5L

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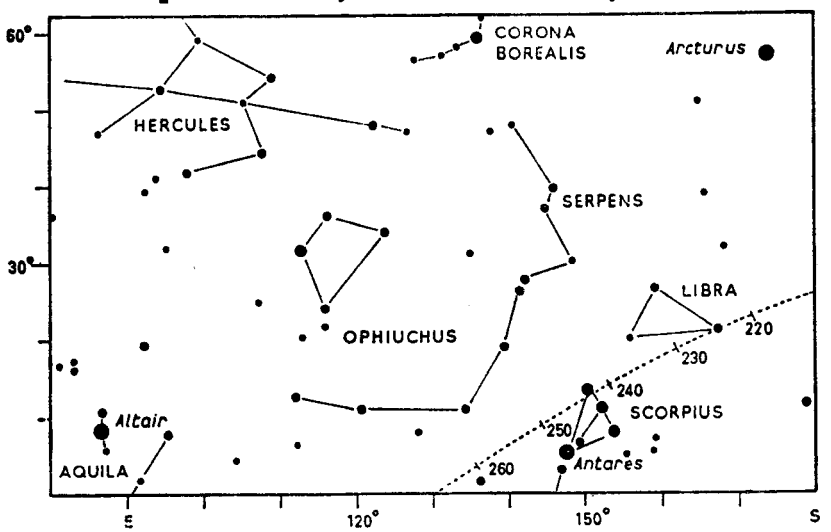
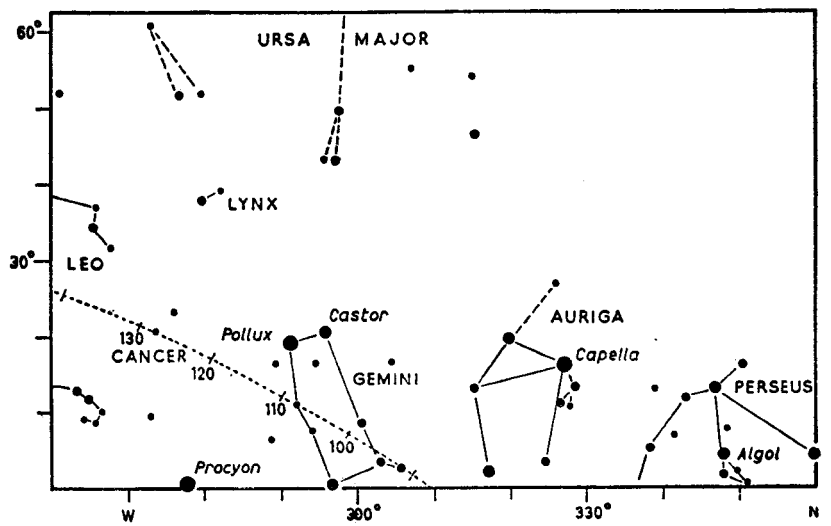
February 6 at	5^h	February 21 at	4^h
March 6 at	3^h	March 21 at	2^h
April 6 at	1^h	April 21 at	midnight
May 6 at	23^h	May 21 at	22^h





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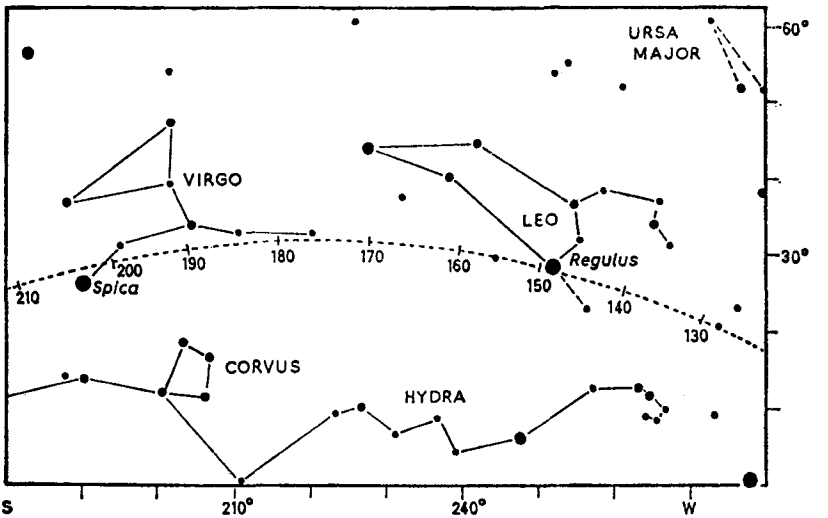
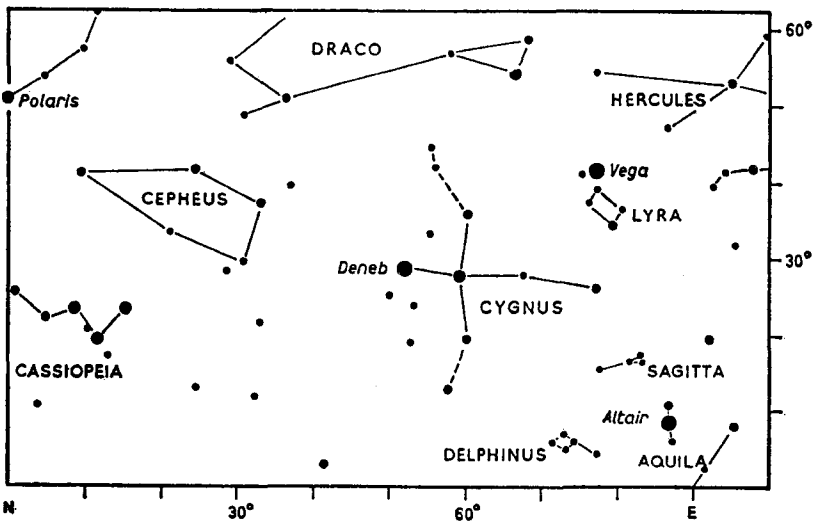
May 6 at	23^h	May 21 at	22^h

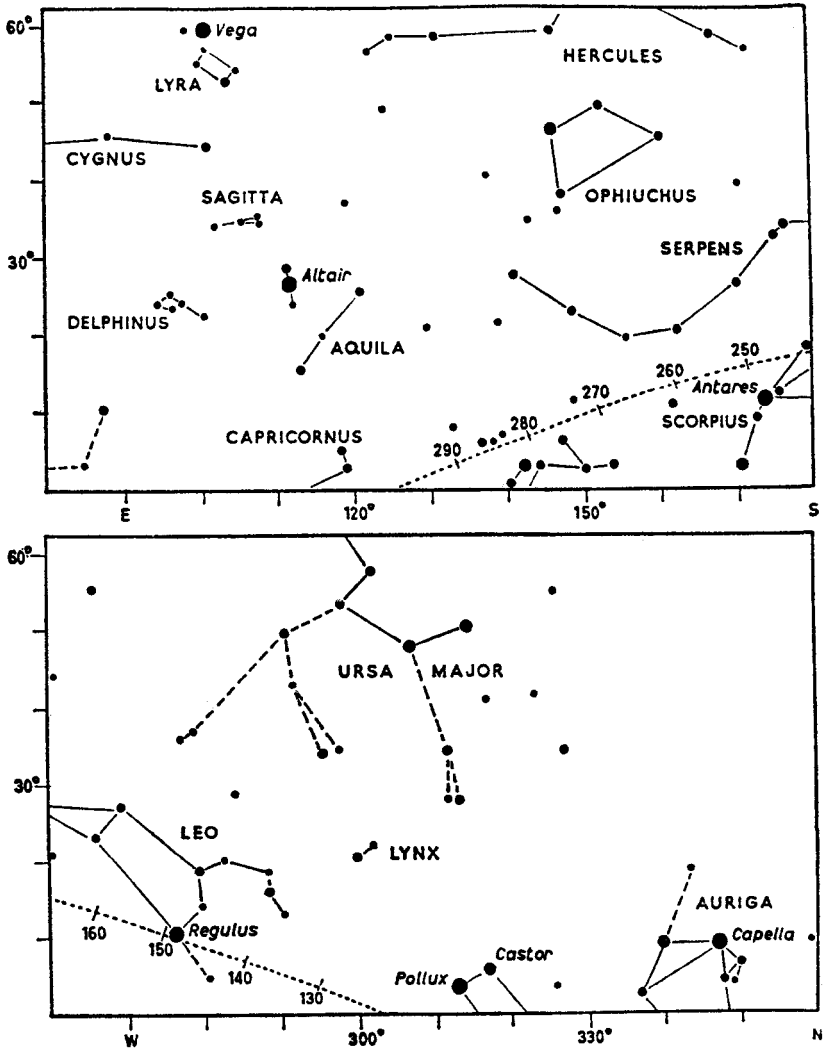
5R





6L

March 6 at 5^h	March 21 at 4^h
April 6 at 3^h	April 21 at 2^h
May 6 at 1^h	May 21 at midnight
June 6 at 23^h	June 21 at 22^h
July 6 at 21^h	July 21 at 20^h



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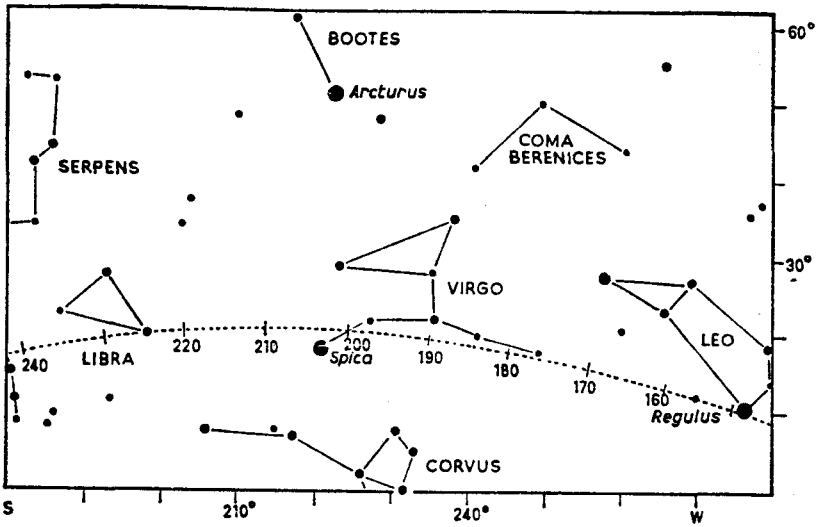
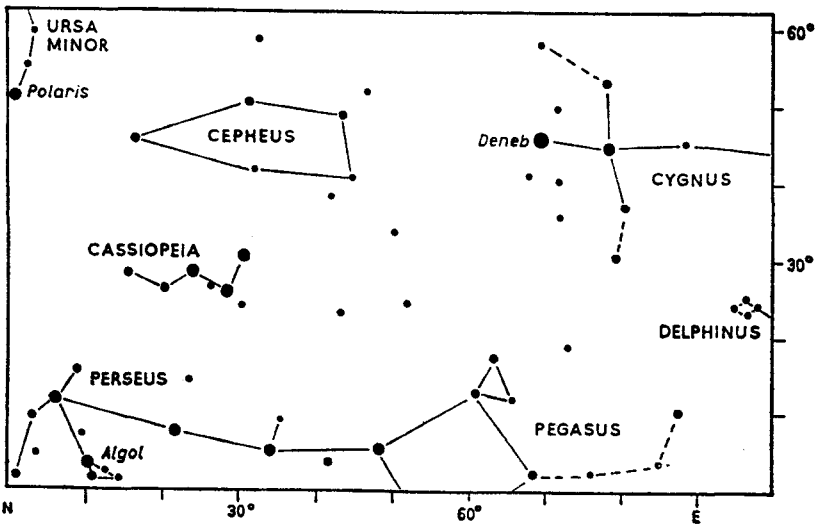
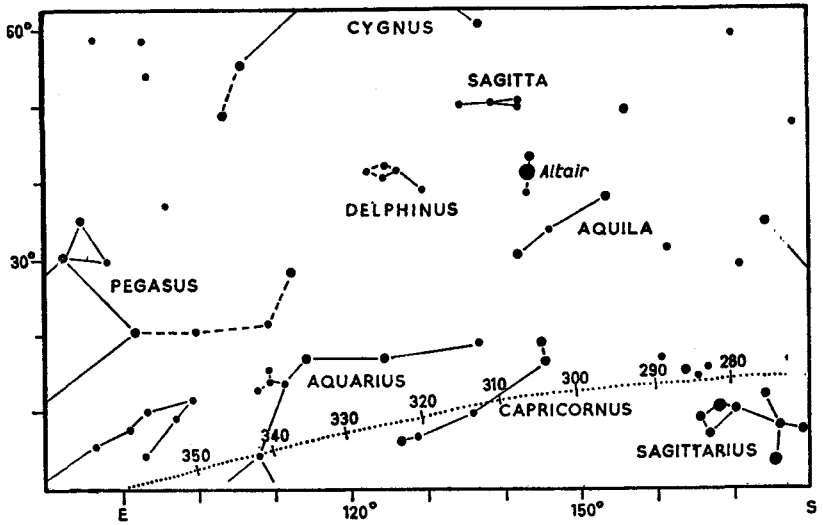
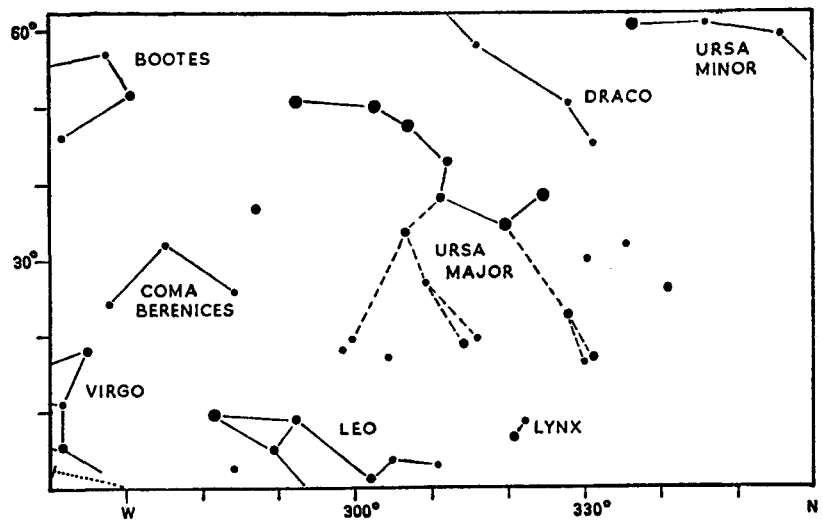




7L

May 6 at 3^h	May 21 at 2^h
June 6 at 1^h	June 21 at midnight
July 6 at 23^h	July 21 at 22^h
August 6 at 21^h	August 21 at 20^h
September 6 at 19^h	September 21 at 18^h





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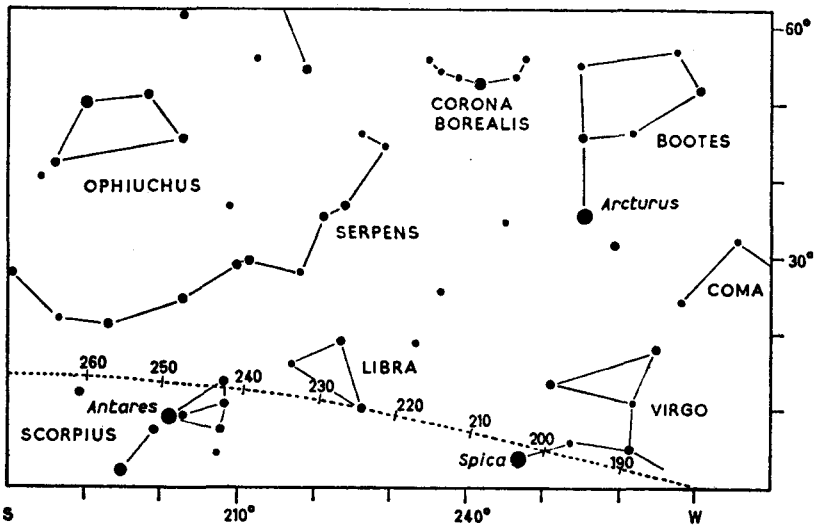
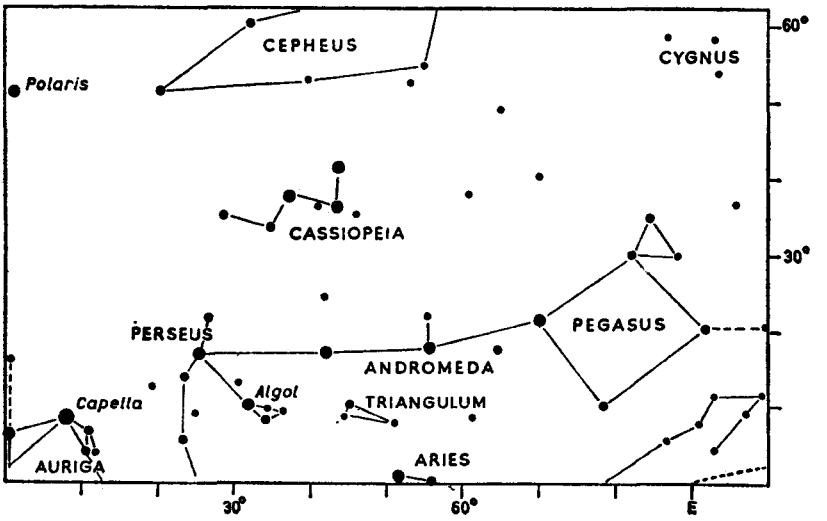
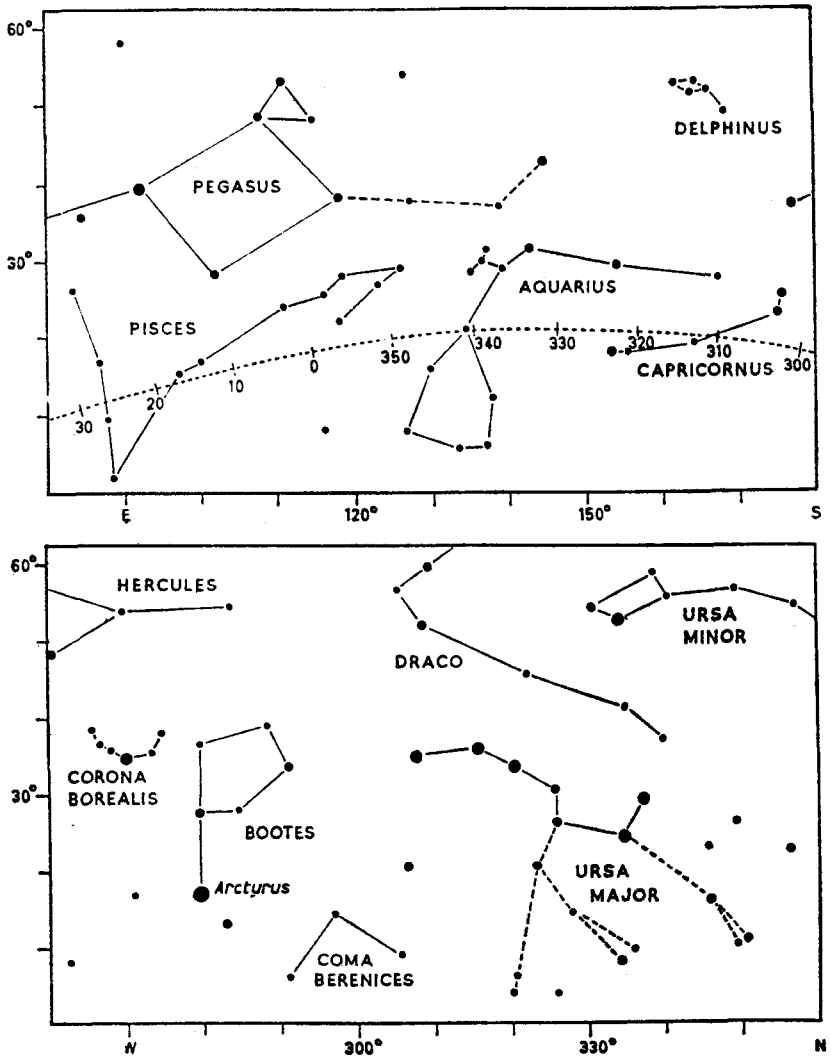




8L

July 6 at 1^h	July 21 at midnight
August 6 at 23^h	August 21 at 22^h
September 6 at 21^h	September 21 at 20^h
October 6 at 19^h	October 21 at 18^h
November 6 at 17^h	November 21 at 16^h



July 6 at 1^h
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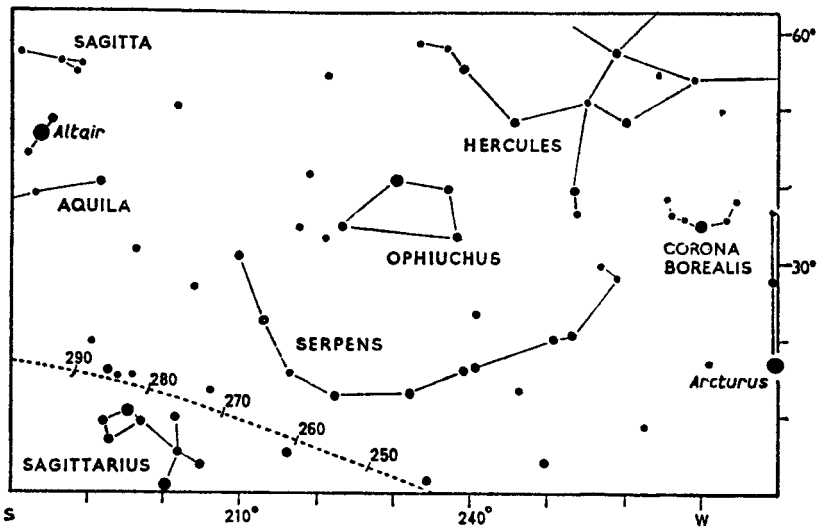
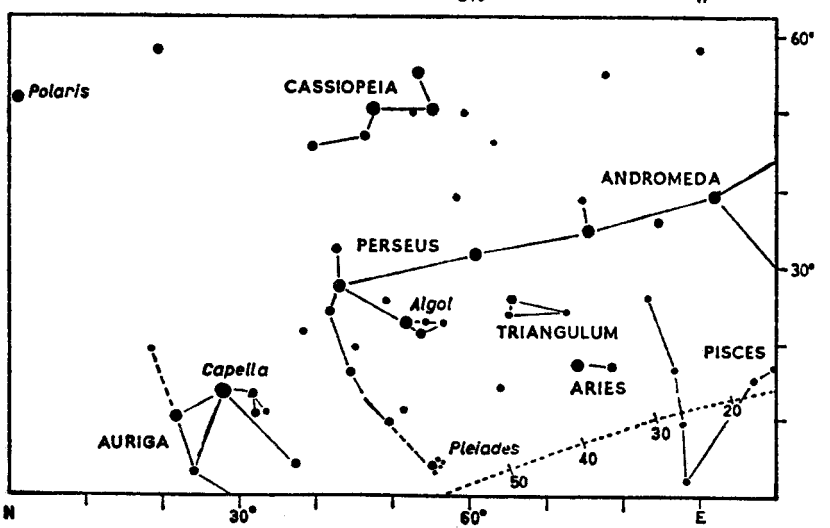
September 6 at 21^h
October 6 at 19^h
November 6 at 17^h

July 21 at midnight
August 21 at 22^h
September 21 at 20^h
October 21 at 18^h
November 21 at 16^h

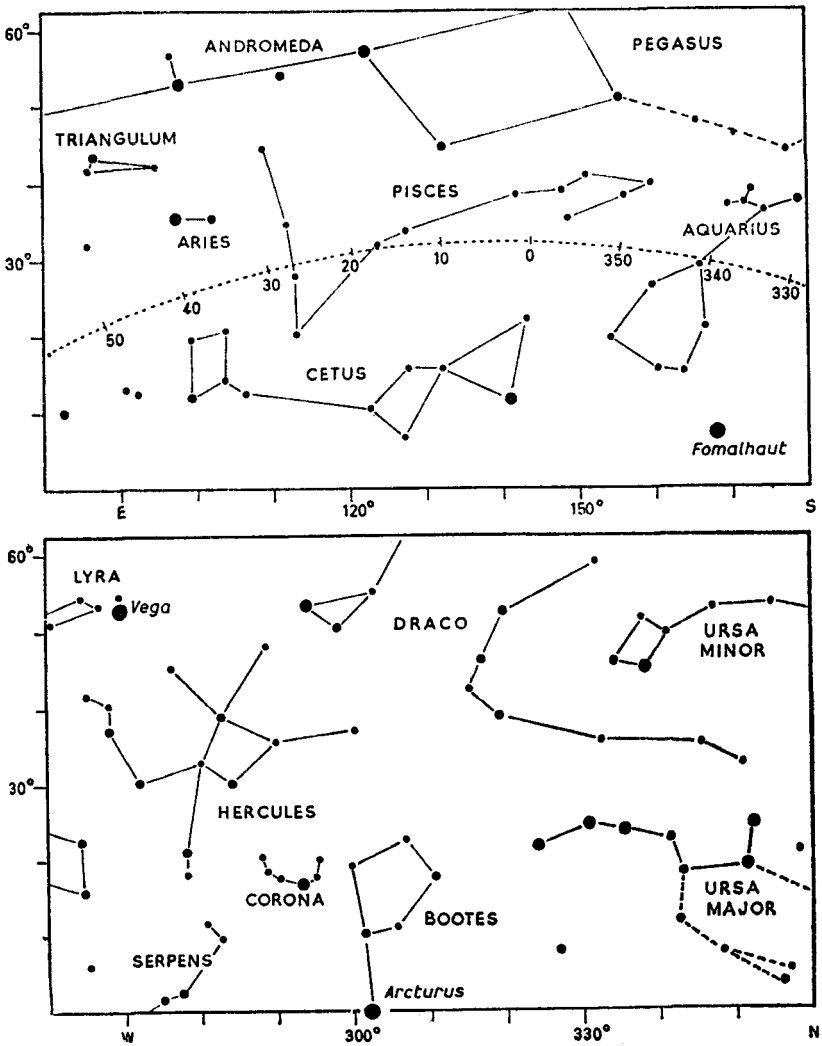
8R





9L

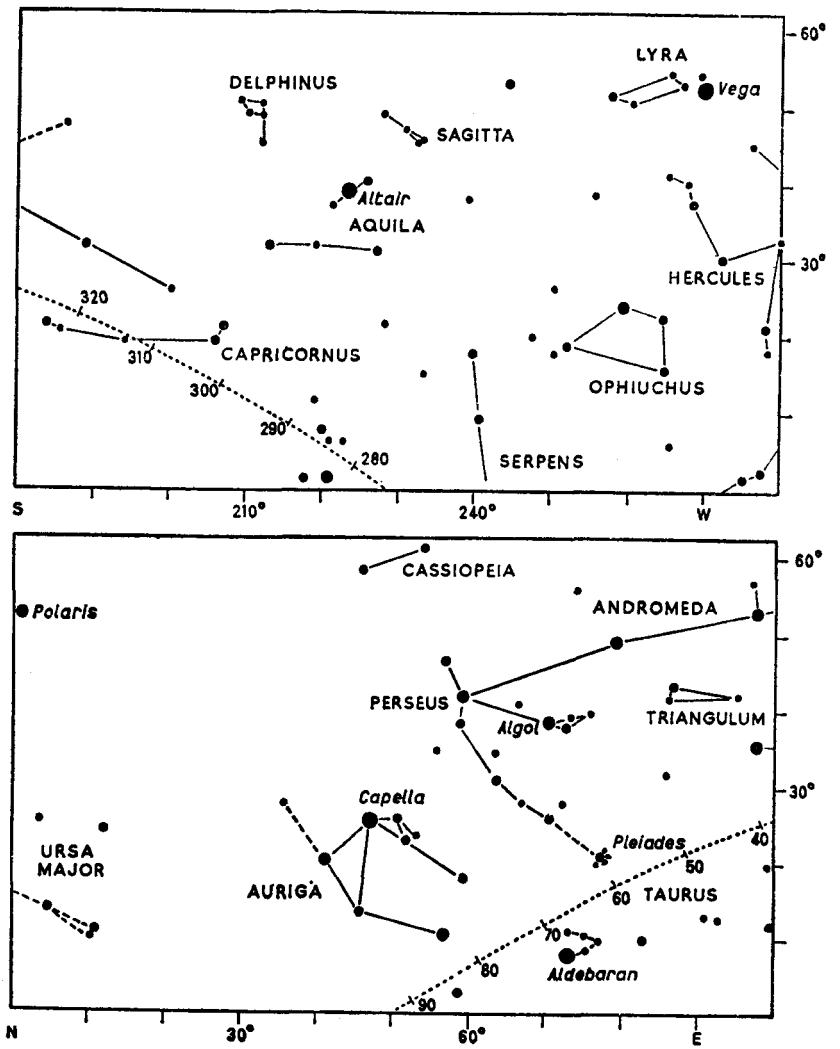
August 6 at 1^h	August 21 at midnight
September 6 at 23^h	September 21 at 22^h
October 6 at 21^h	October 21 at 20^h
November 6 at 19^h	November 21 at 18^h
December 6 at 17^h	December 21 at 16^h



August 6 at 1h
September 6 at 23h
October 6 at 21h
November 6 at 19h
December 6 at 17h

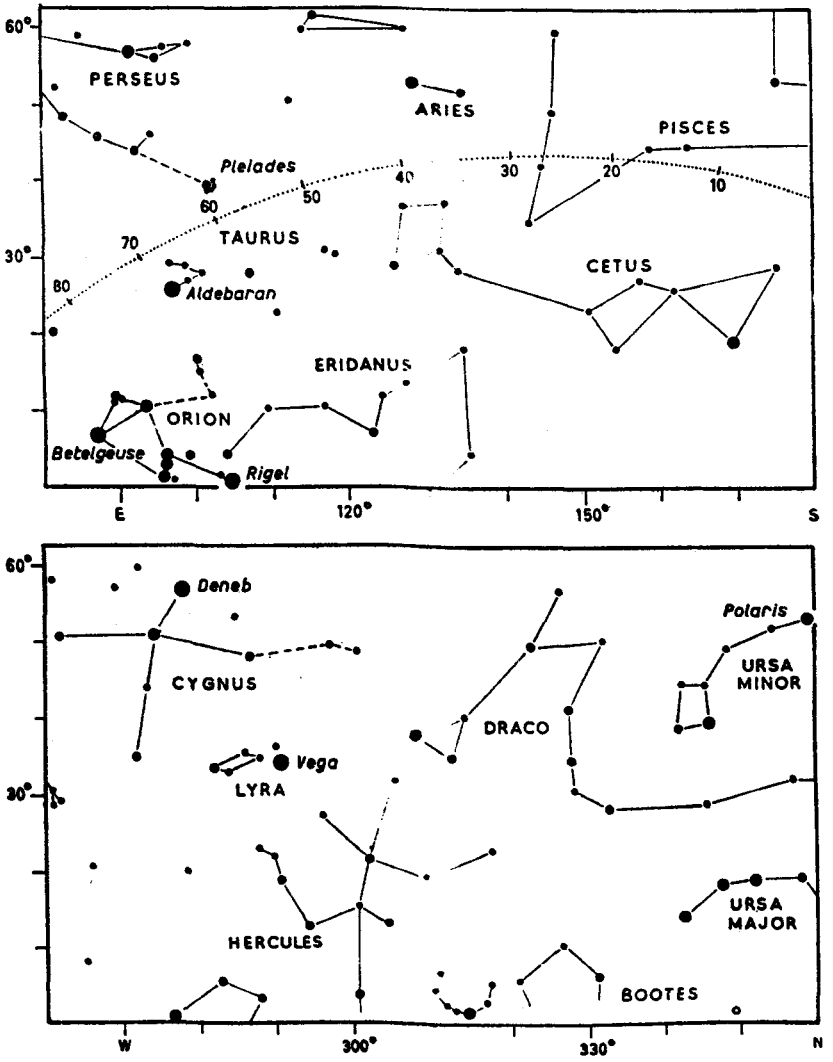
August 21 at midnight
September 21 at 22h
October 21 at 20h
November 21 at 18h
December 21 at 16h

9R



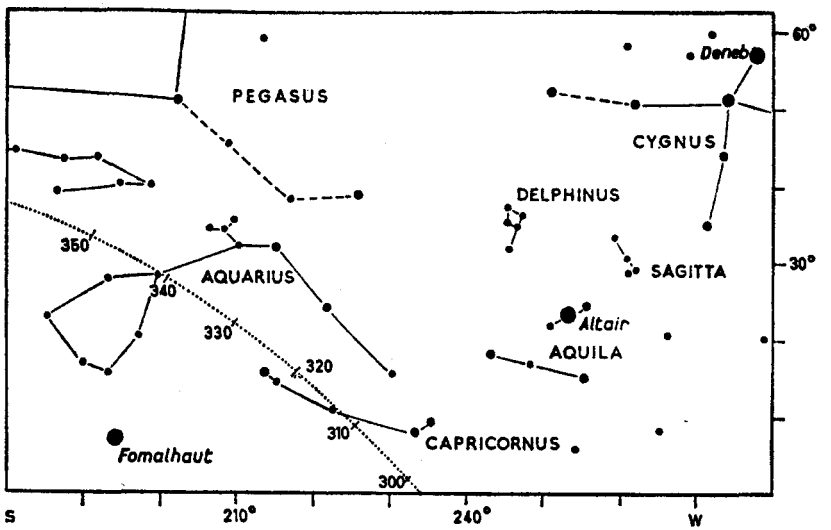
10L

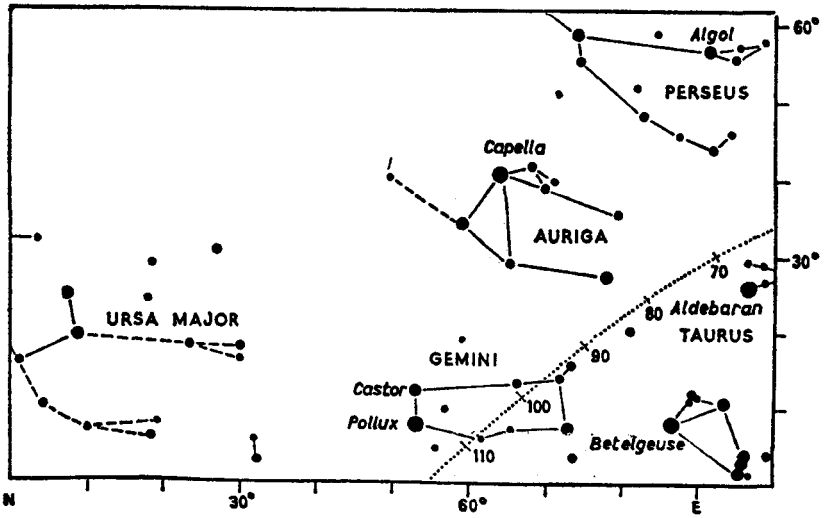
August 6 at 3^h	August 21 at 2^h
September 6 at 1^h	September 21 at midnight
October 6 at 23^h	October 21 at 22^h
November 6 at 21^h	November 21 at 20^h
December 6 at 19^h	December 21 at 18^h



August 6 at	3^h	August 21 at	2^h
September 6 at	1^h	September 21 at	midnight
October 6 at	23^h	October 21 at	22^h
November 6 at	21^h	November 21 at	20^h
December 6 at	19^h	December 21 at	18^h

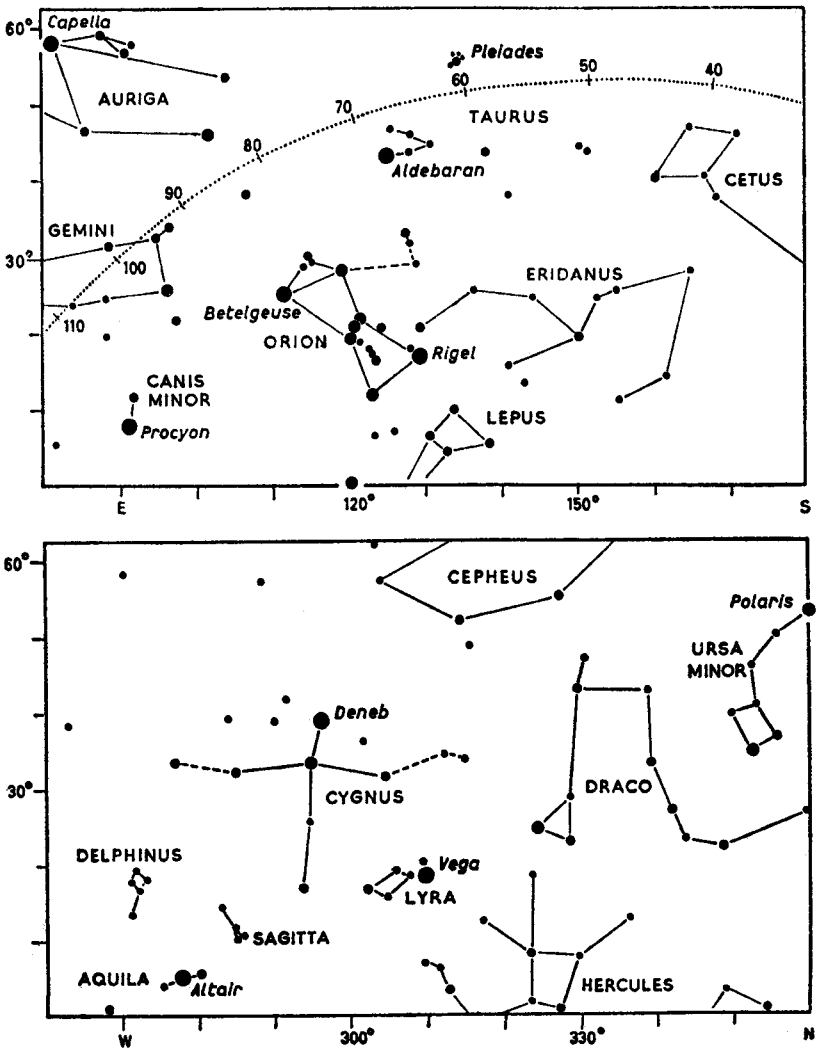
10R





11L

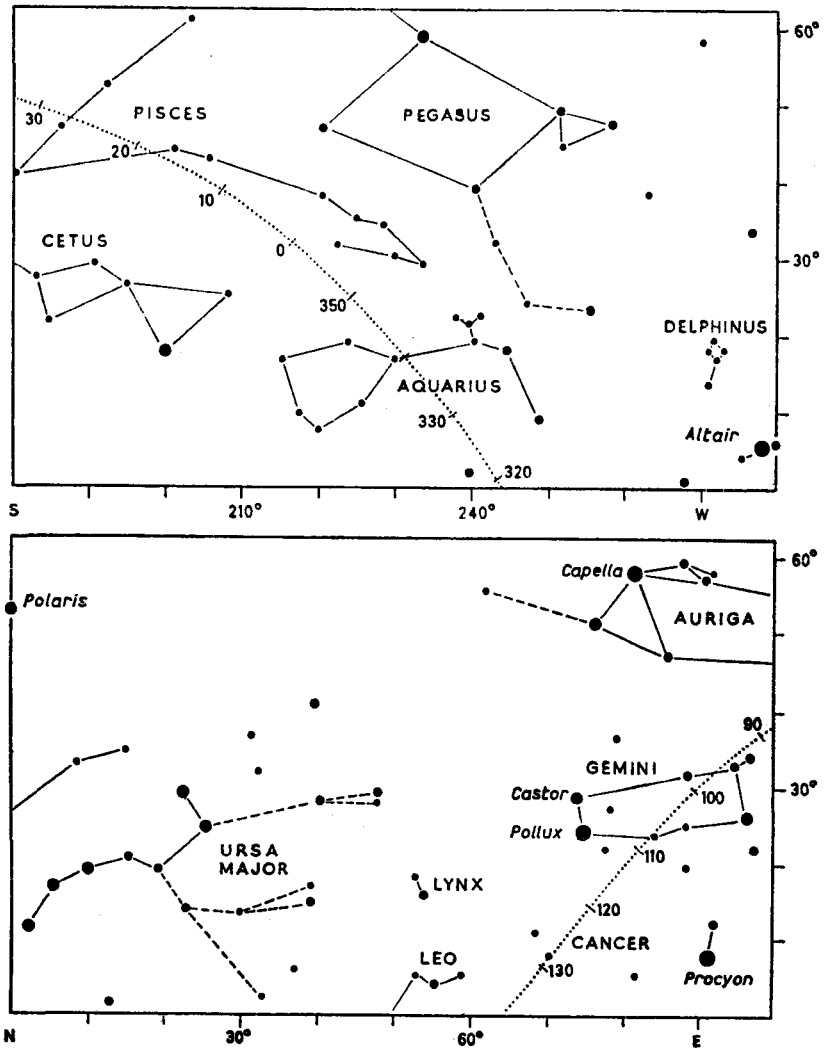
September 6 at	3^h	September 21 at	2^h
October 6 at	1^h	October 21 at	midnight
November 6 at	23^h	November 21 at	22^h
December 6 at	21^h	December 21 at	20^h
January 6 at	19^h	January 21 at	18^h



September 6 at 3^h
October 6 at 1^h
November 6 at 23^h
December 6 at 21^h
January 6 at 19^h

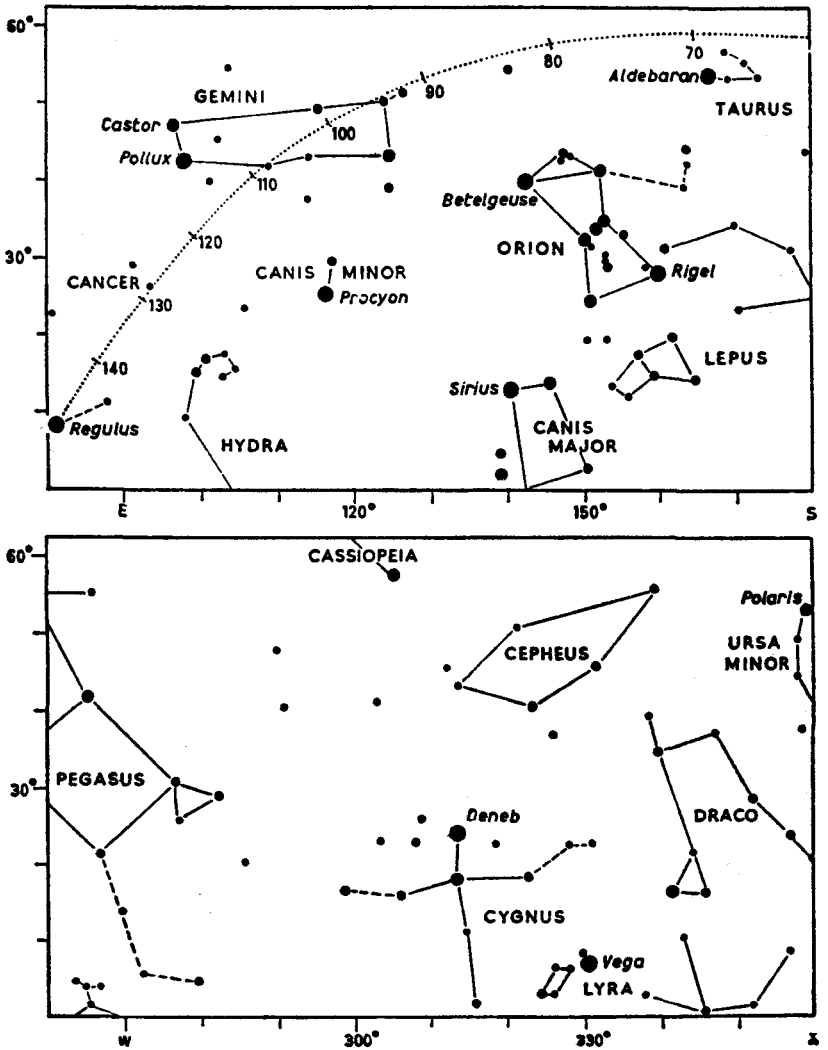
September 21 at 2^h
October 21 at midnight
November 21 at 22^h
December 21 at 20^h
January 21 at 18^h

11R

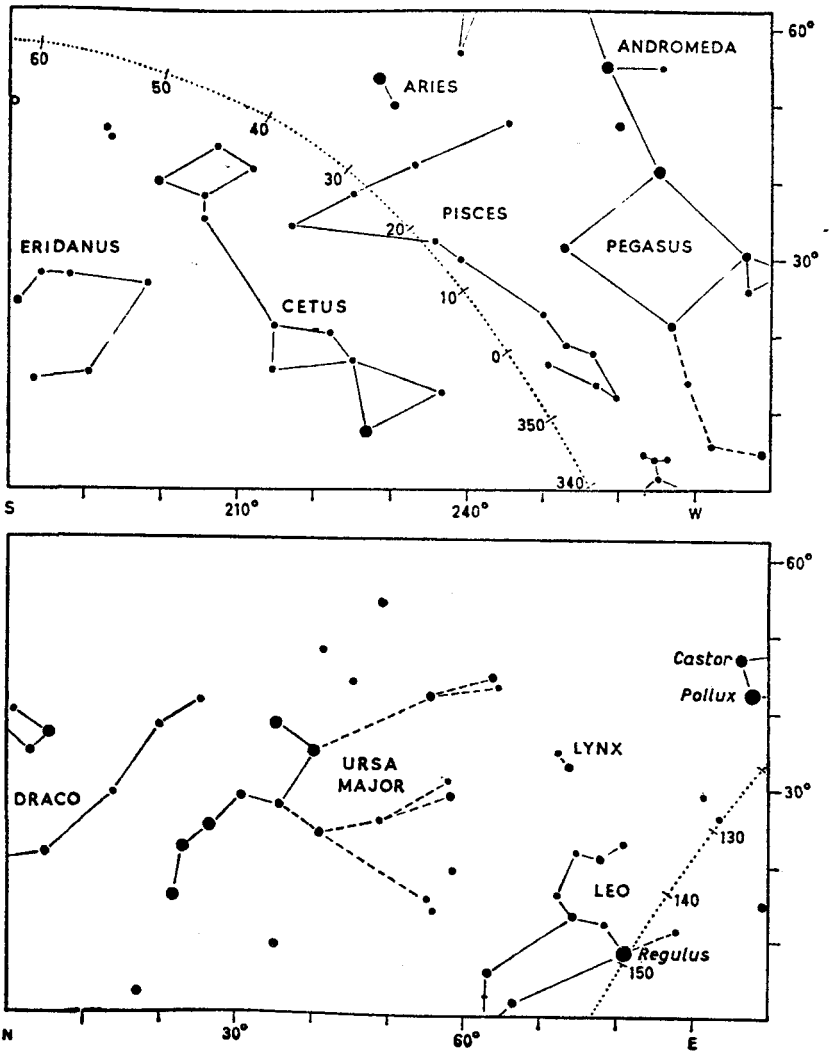


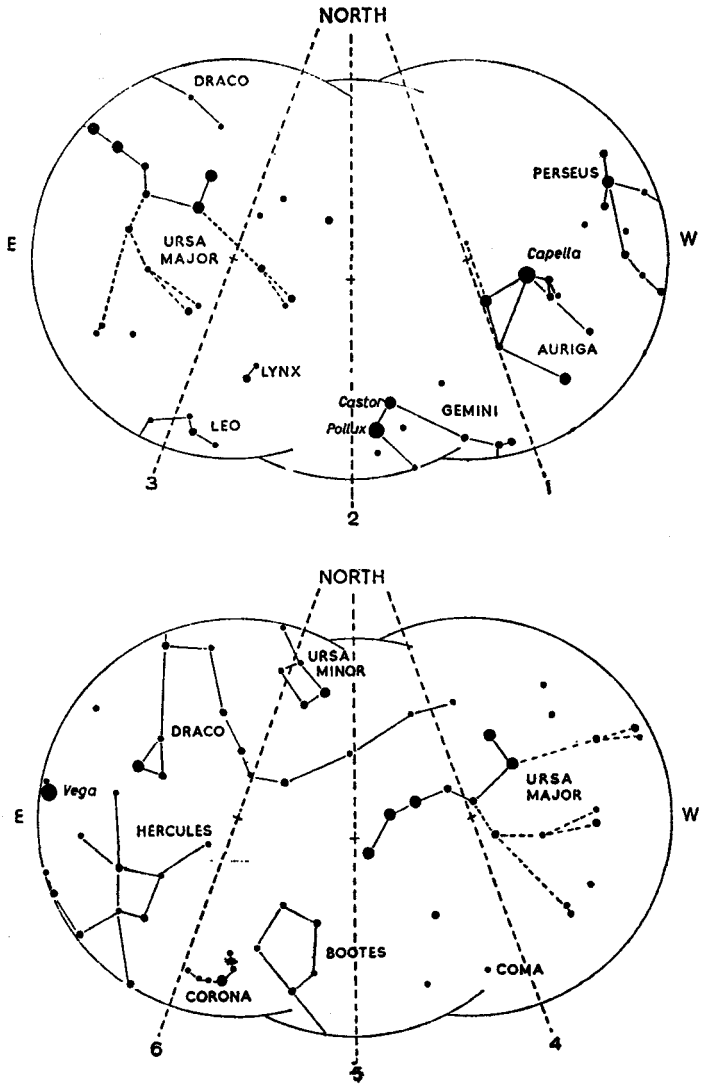
12L

October 6 at 3^h	October 21 at 2^h
November 6 at 1^h	November 21 at midnight
December 6 at 23^h	December 21 at 22^h
January 6 at 21^h	January 21 at 20^h
February 6 at 19^h	February 21 at 18^h

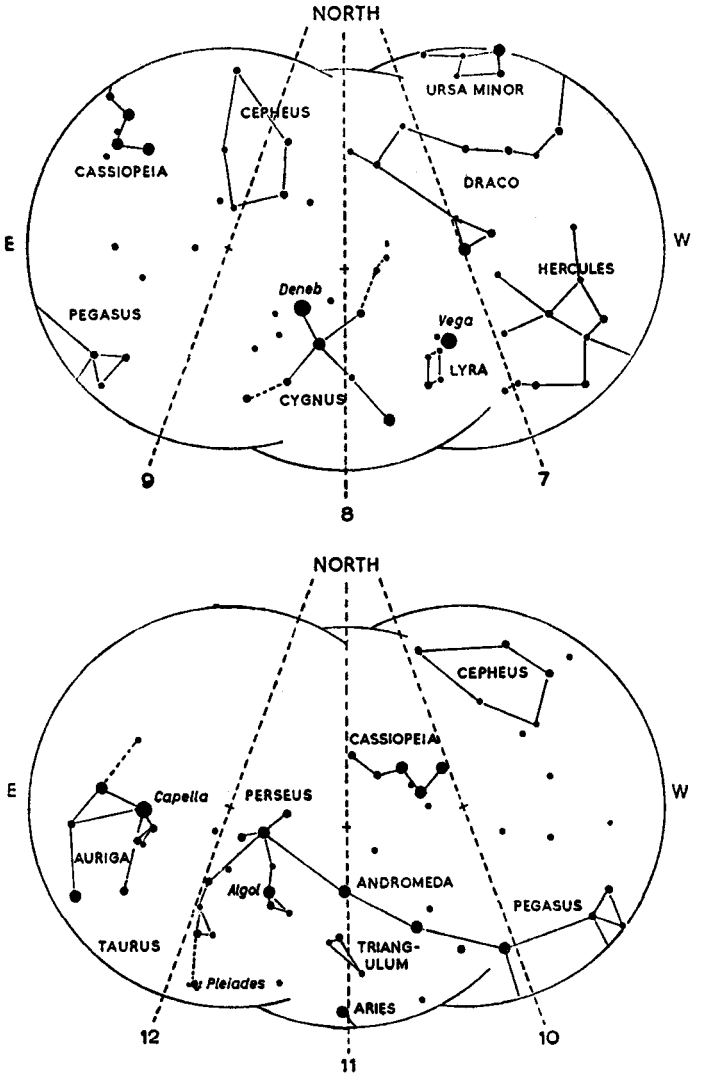


October 6 at 3^h	October 21 at 2^h	**12R**
November 6 at 1^h	November 21 at midnight	
December 6 at 23^h	December 21 at 22^h	
January 6 at 21^h	January 21 at 20^h	
February 6 at 19^h	February 21 at 18^h	





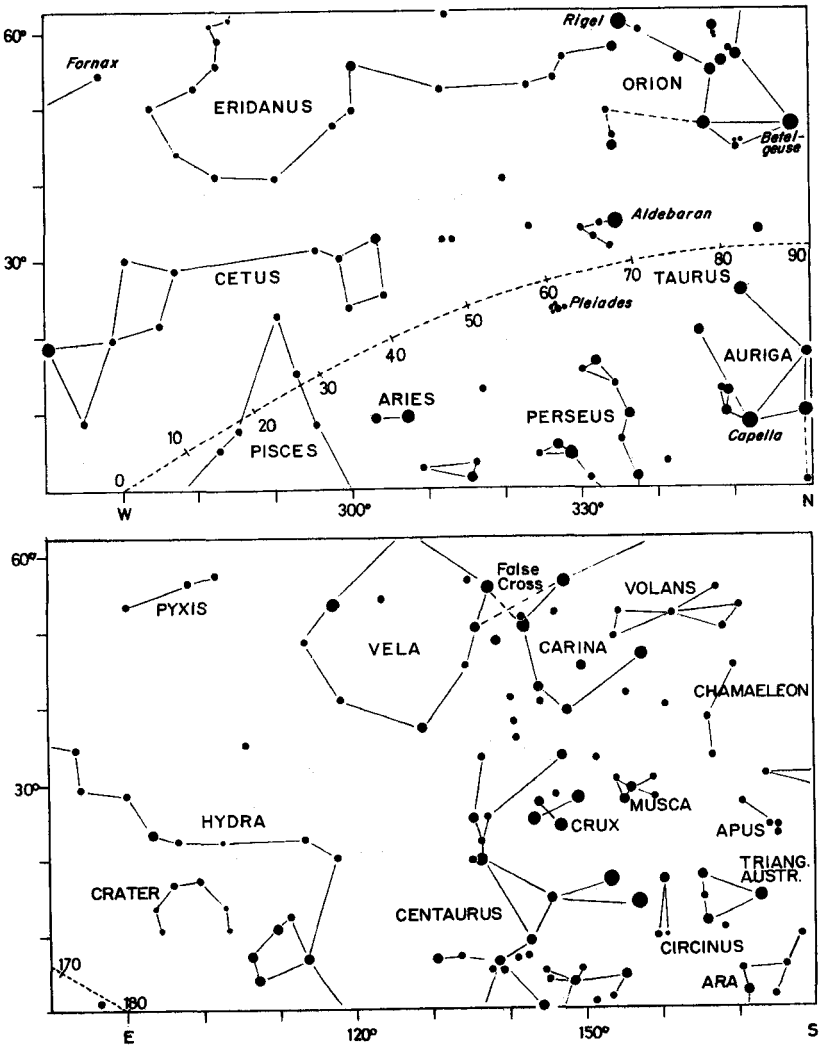
Northern Hemisphere Overhead Stars



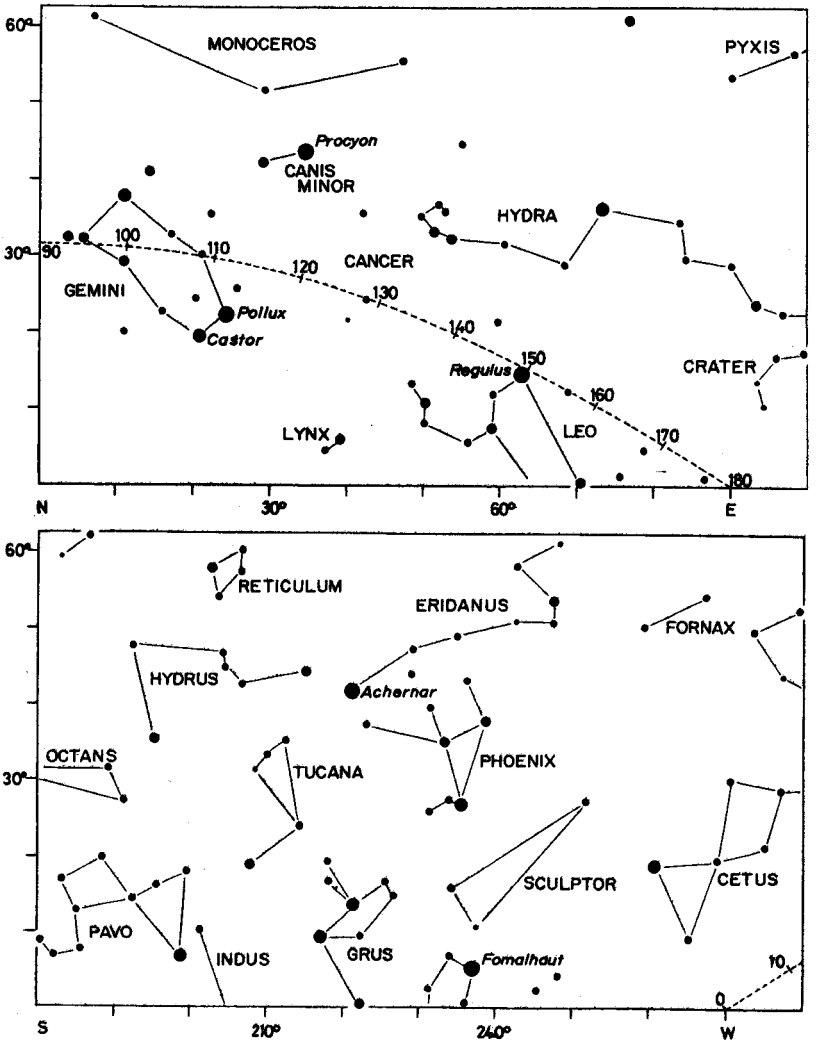
Northern Hemisphere Overhead Stars

1L

October 6 at	5^h	October 21 at	4^h
November 6 at	3^h	November 21 at	2^h
December 6 at	1^h	December 21 at	midnight
January 6 at	23^h	January 21 at	22^h
February 6 at	21^h	February 21 at	20^h

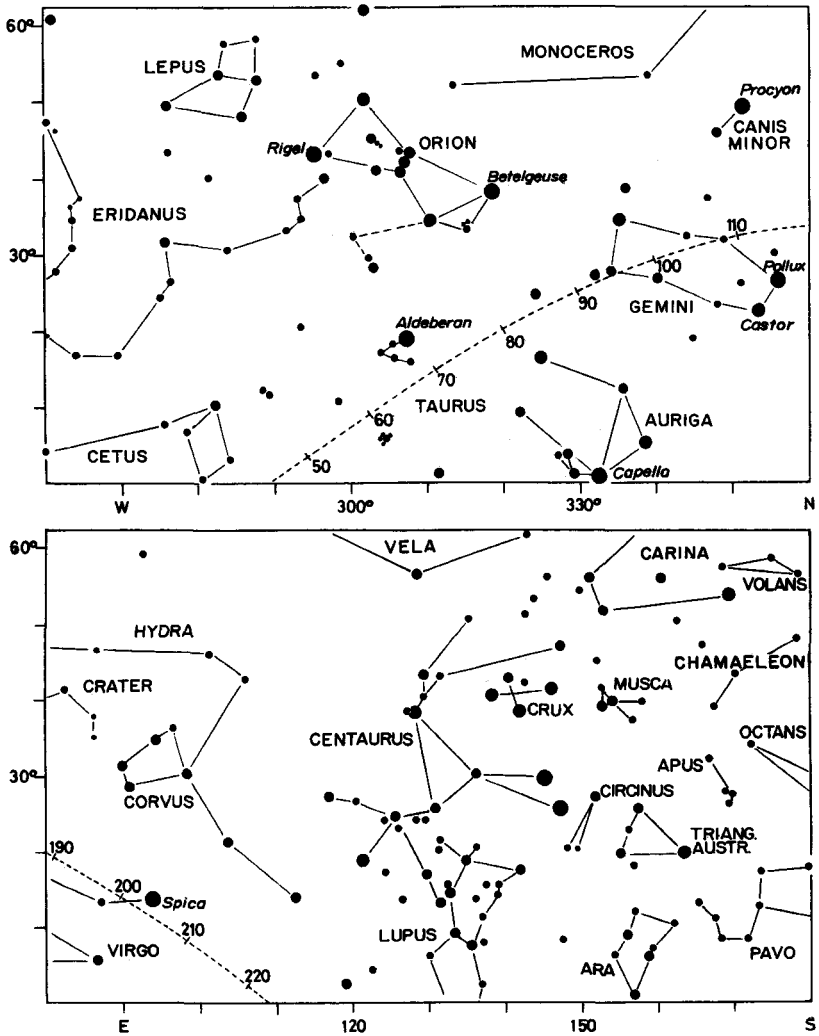


October 6 at 5^h	October 21 at 4^h	**1R**
November 6 at 3^h	November 21 at 2^h	
December 6 at 1^h	December 21 at midnight	
January 6 at 23^h	January 21 at 22^h	
February 6 at 21^h	February 21 at 20^h	



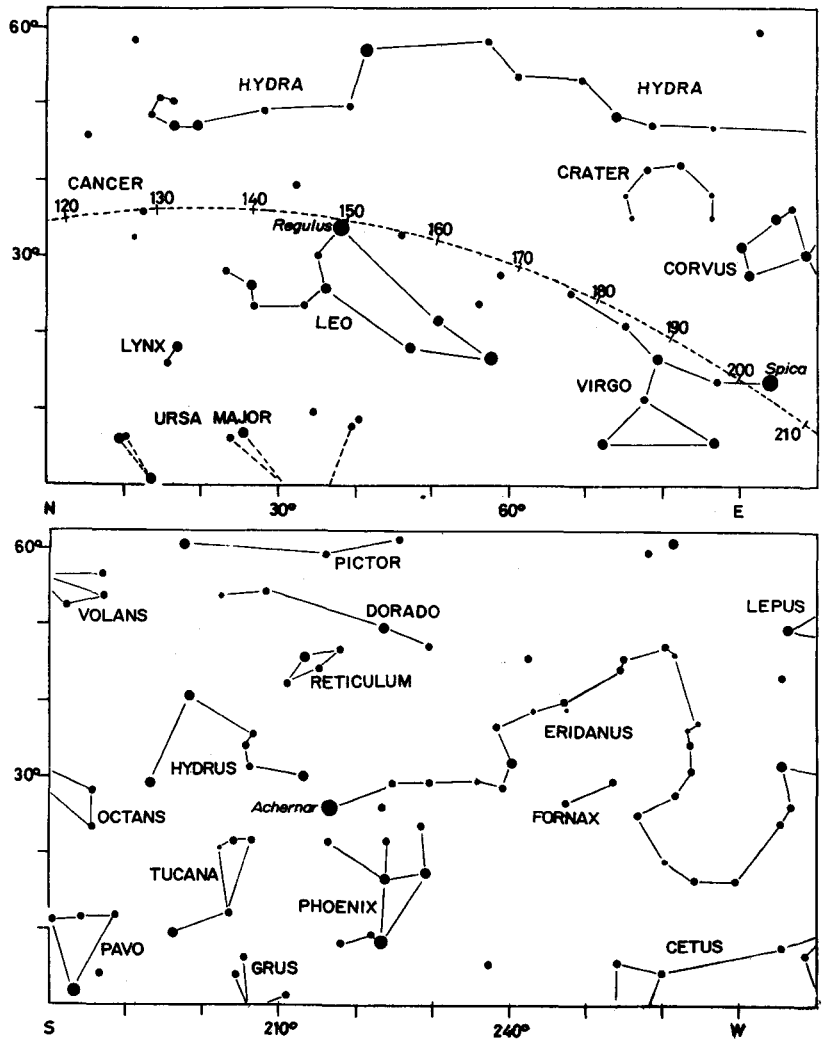
2L

November 6 at 5^h	November 21 at 4^h
December 6 at 3^h	December 21 at 2^h
January 6 at 1^h	January 21 at midnight
February 6 at 23^h	February 21 at 22^h
March 6 at 21^h	March 21 at 20^h



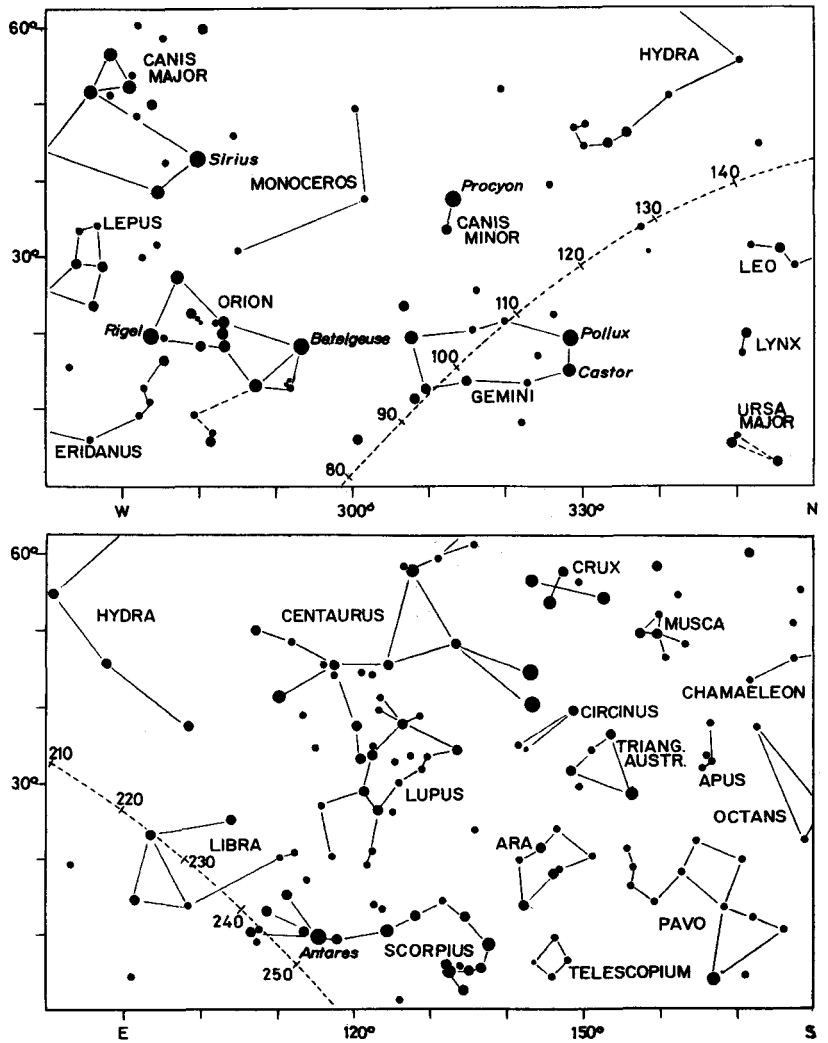
November 6 at 5^h	November 21 at 4^h
December 6 at 3^h	December 21 at 2^h
January 6 at 1^h	January 21 at midnight
February 6 at 23^h	February 21 at 22^h
March 6 at 21^h	March 21 at 20^h

2R



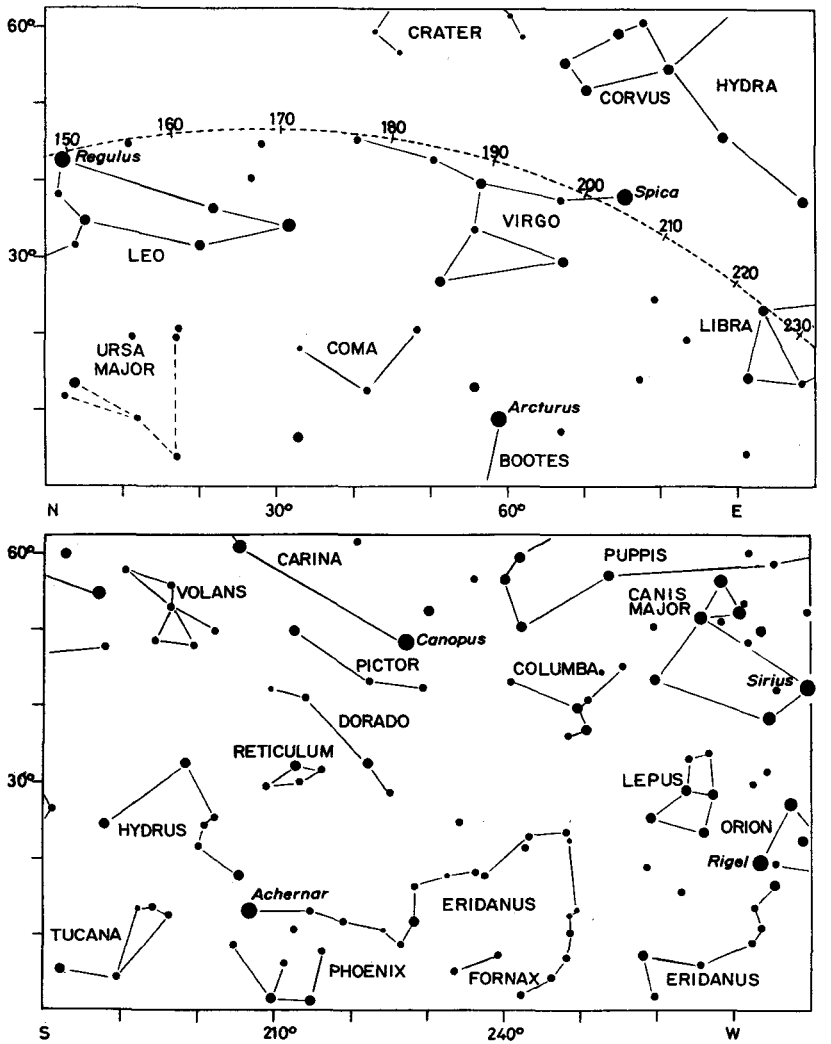
3L

January 6 at 3^h	January 21 at 2^h
February 6 at 1^h	February 21 at midnight
March 6 at 23^h	March 21 at 22^h
April 6 at 21^h	April 21 at 20^h
May 6 at 19^h	May 21 at 18^h



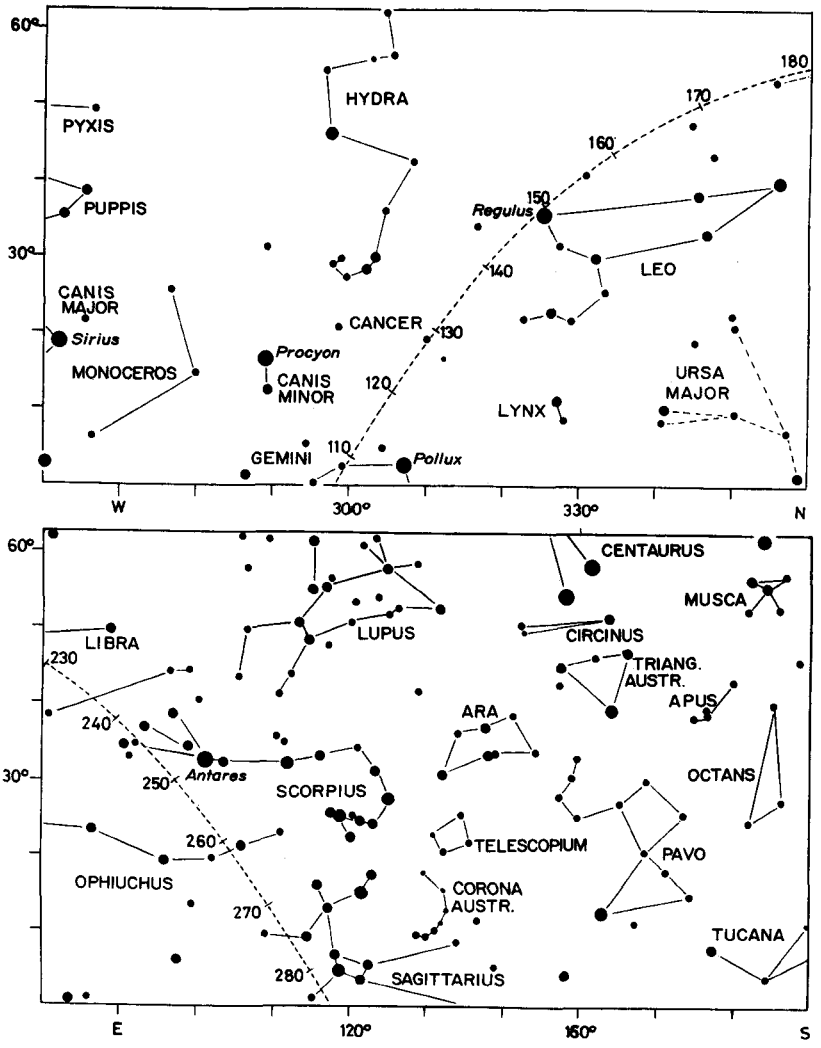
January 6 at	3^h	January 21 at	2^h
February 6 at	1^h	February 21 at	midnight
March 6 at	23^h	March 21 at	22^h
April 6 at	21^h	April 21 at	20^h
May 6 at	19^h	May 21 at	18^h

3R



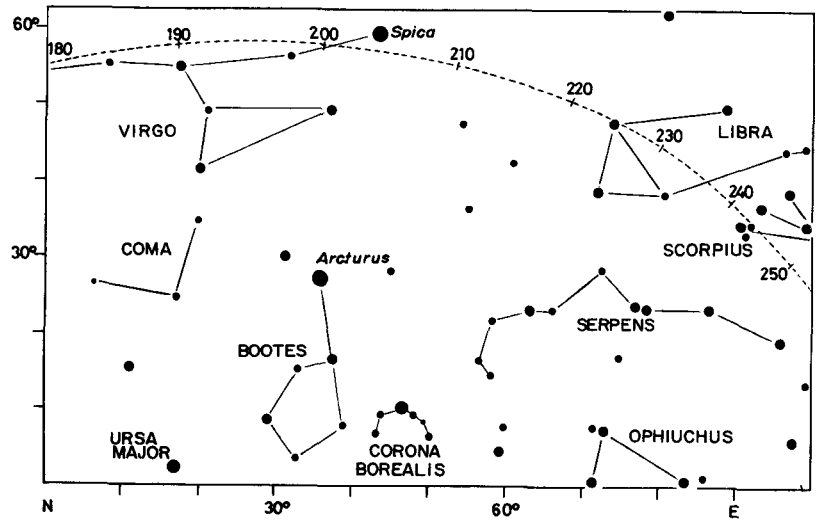
4L

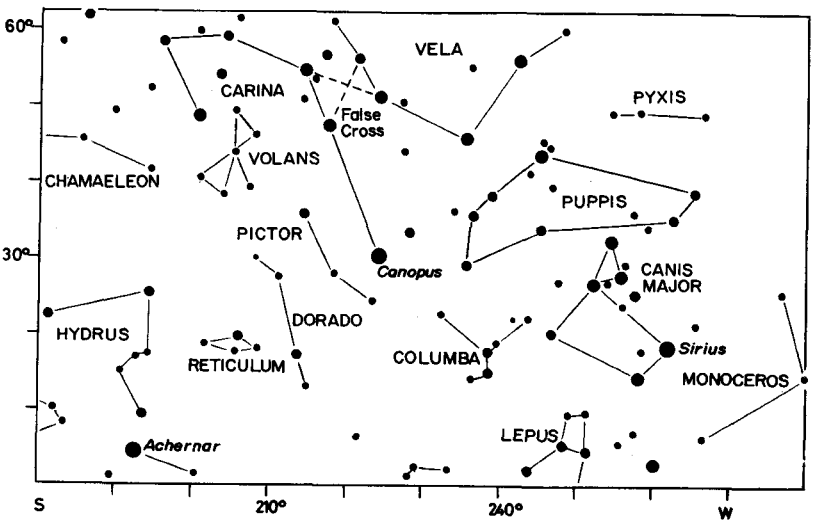
February 6 at 3^h	February 21 at 2^h
March 6 at 1^h	March 21 at midnight
April 6 at 23^h	April 21 at 22^h
May 6 at 21^h	May 21 at 20^h
June 6 at 19^h	June 21 at 18^h



February 6 at 3^h	February 21 at 2^h
March 6 at 1^h	March 21 at midnight
April 6 at 23^h	April 21 at 22^h
May 6 at 21^h	May 21 at 20^h
June 6 at 19^h	June 21 at 18^h

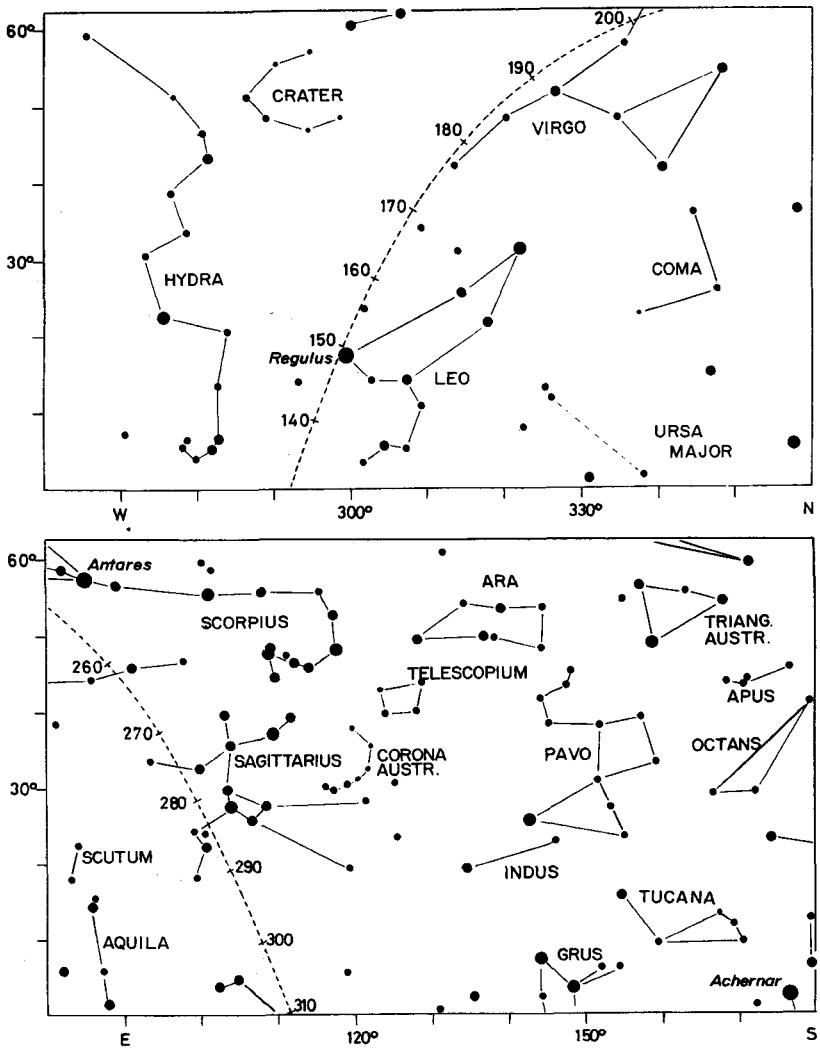
4R





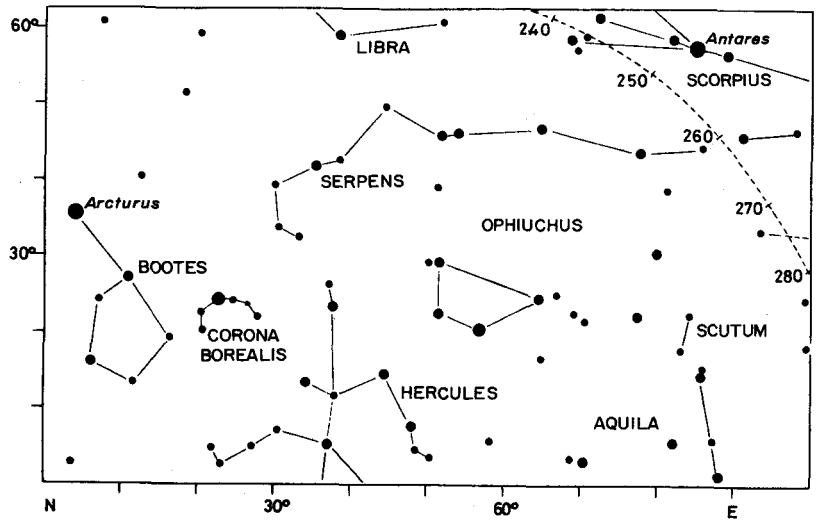
5L

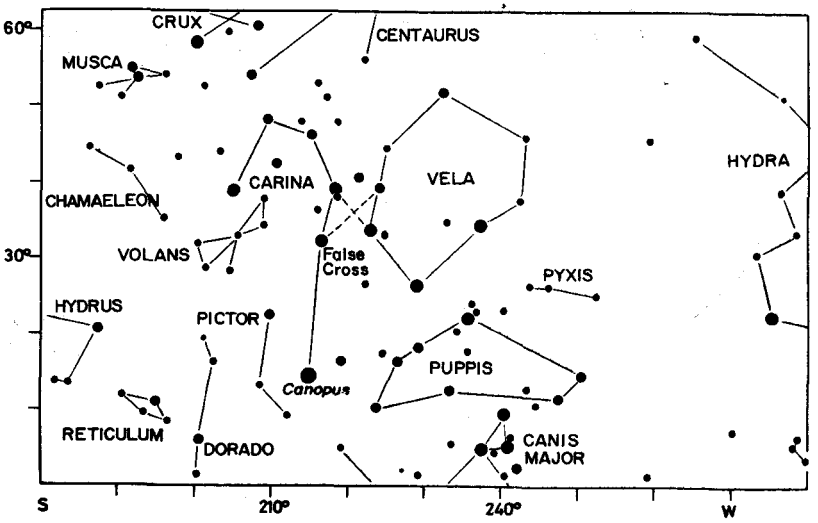
March 6 at 3^h	March 21 at 2^h
April 6 at 1^h	April 21 at midnight
May 6 at 23^h	May 21 at 22^h
June 6 at 21^h	June 21 at 20^h
July 6 at 19^h	July 21 at 18^h



March 6 at 3^h	March 21 at 2^h
April 6 at 1^h	April 21 at midnight
May 6 at 23^h	May 21 at 22^h
June 6 at 21^h	June 21 at 20^h
July 6 at 19^h	July 21 at 18^h

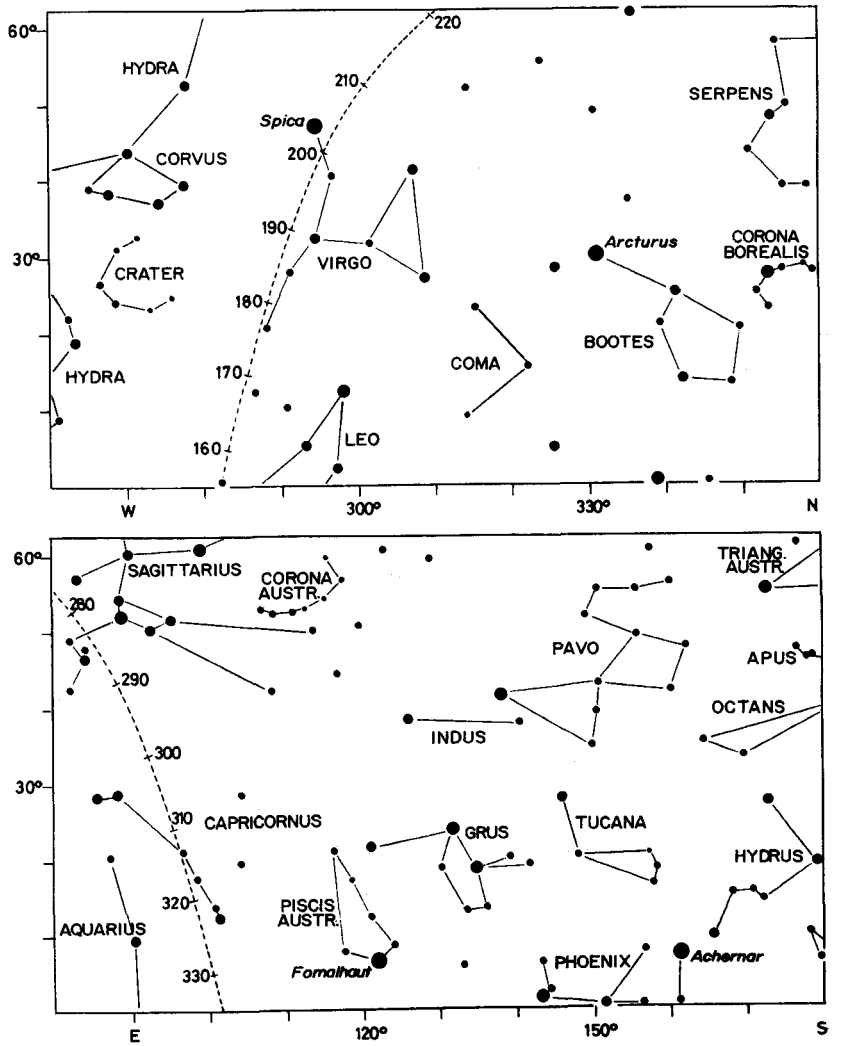
5R





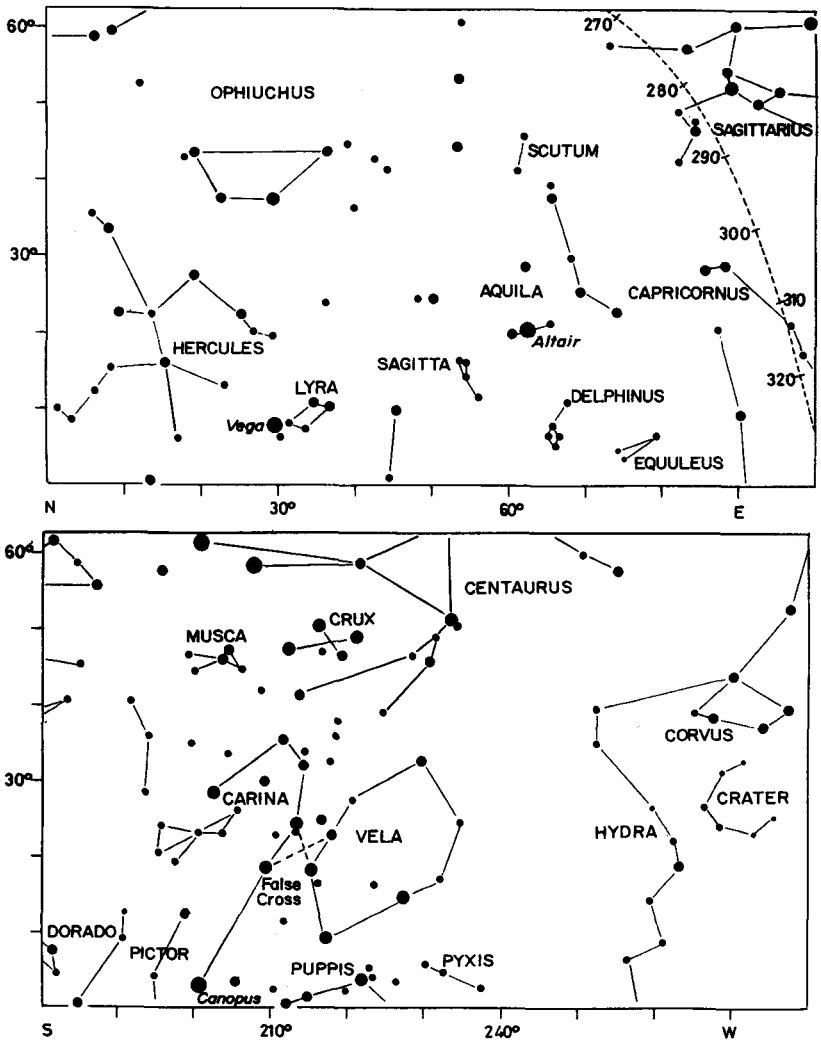
6L

March 6 at 5^h	March 21 at 4^h
April 6 at 3^h	April 21 at 2^h
May 6 at 1^h	May 21 at midnight
June 6 at 23^h	June 21 at 22^h
July 6 at 21^h	July 21 at 20^h



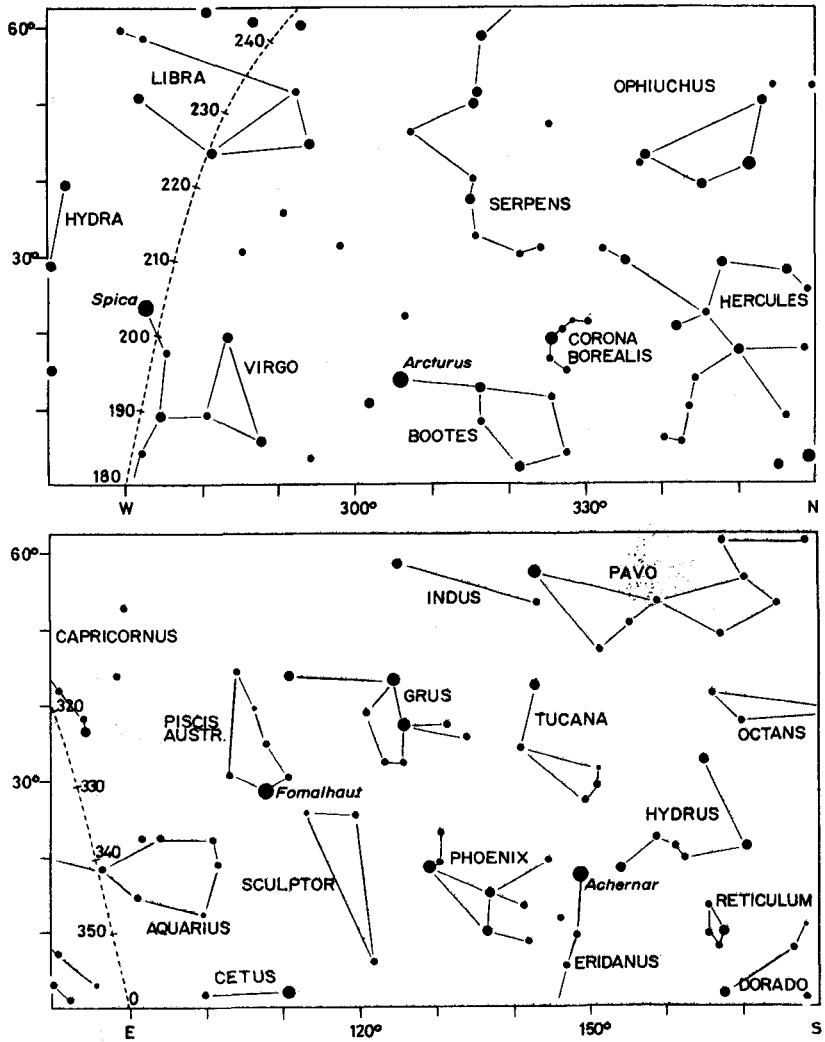
March 6 at	5^h	March 21 at	4^h
April 6 at	3^h	April 21 at	2^h
May 6 at	1^h	May 21 at	midnight
June 6 at	23^h	June 21 at	22^h
July 6 at	21^h	July 21 at	20^h

6R



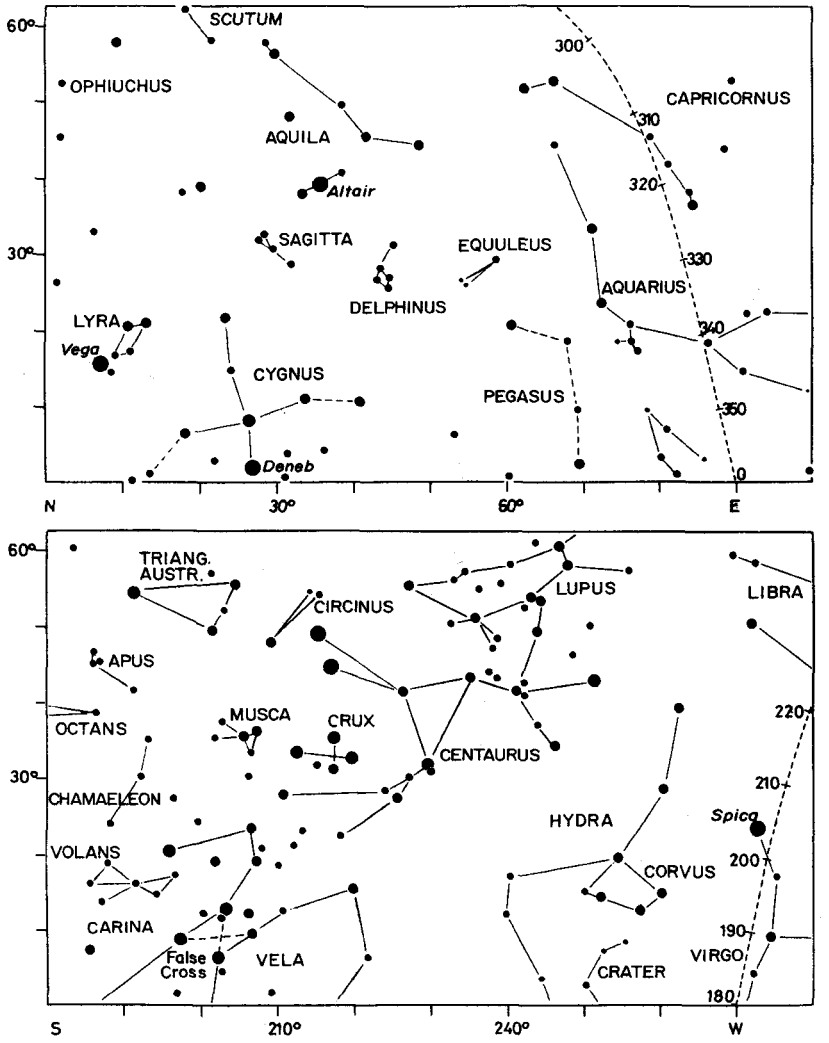
7L

April 6 at 5^h	April 21 at 4^h
May 6 at 3^h	May 21 at 2^h
June 6 at 1^h	June 21 at midnight
July 6 at 23^h	July 21 at 22^h
August 6 at 21^h	August 21 at 20^h



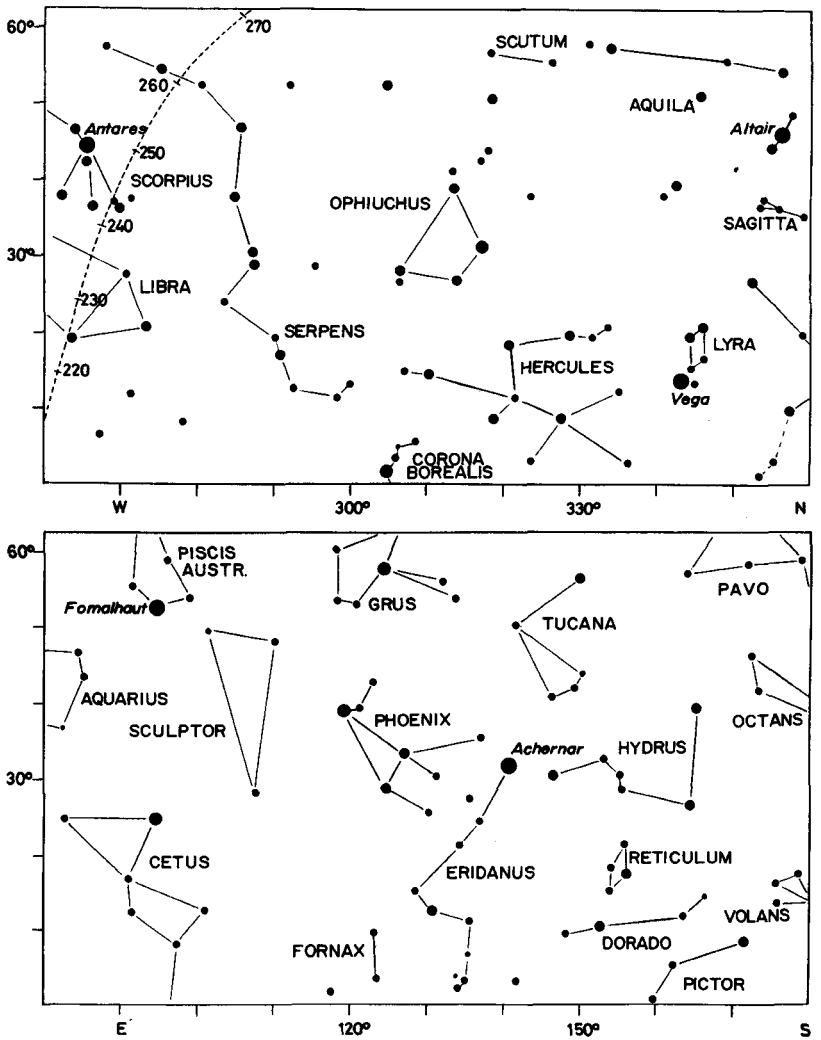
April 6 at 5^h	April 21 at 4^h
May 6 at 3^h	May 21 at 2^h
June 6 at 1^h	June 21 at midnight
July 6 at 23^h	July 21 at 22^h
August 6 at 21^h	August 21 at 20^h

7R

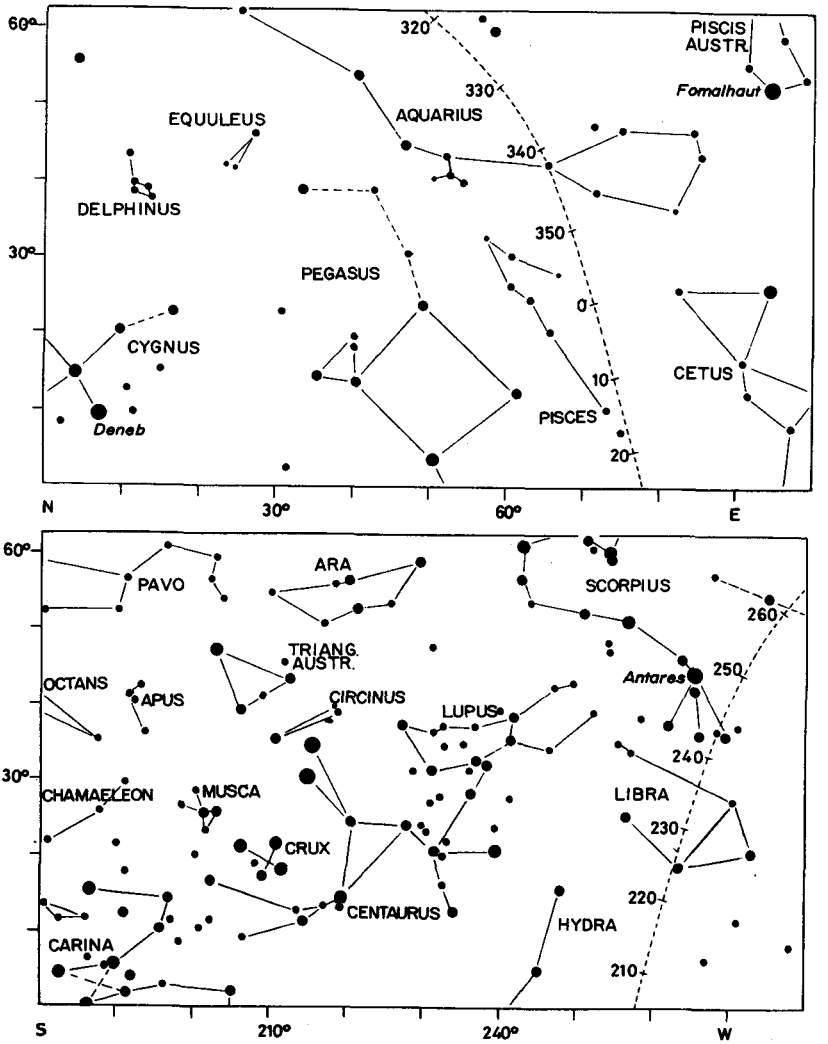


8L

May 6 at 5^h	May 21 at 4^h
June 6 at 3^h	June 21 at 2^h
July 6 at 1^h	July 21 at midnight
August 6 at 23^h	August 21 at 22^h
September 6 at 21^h	September 21 at 20^h

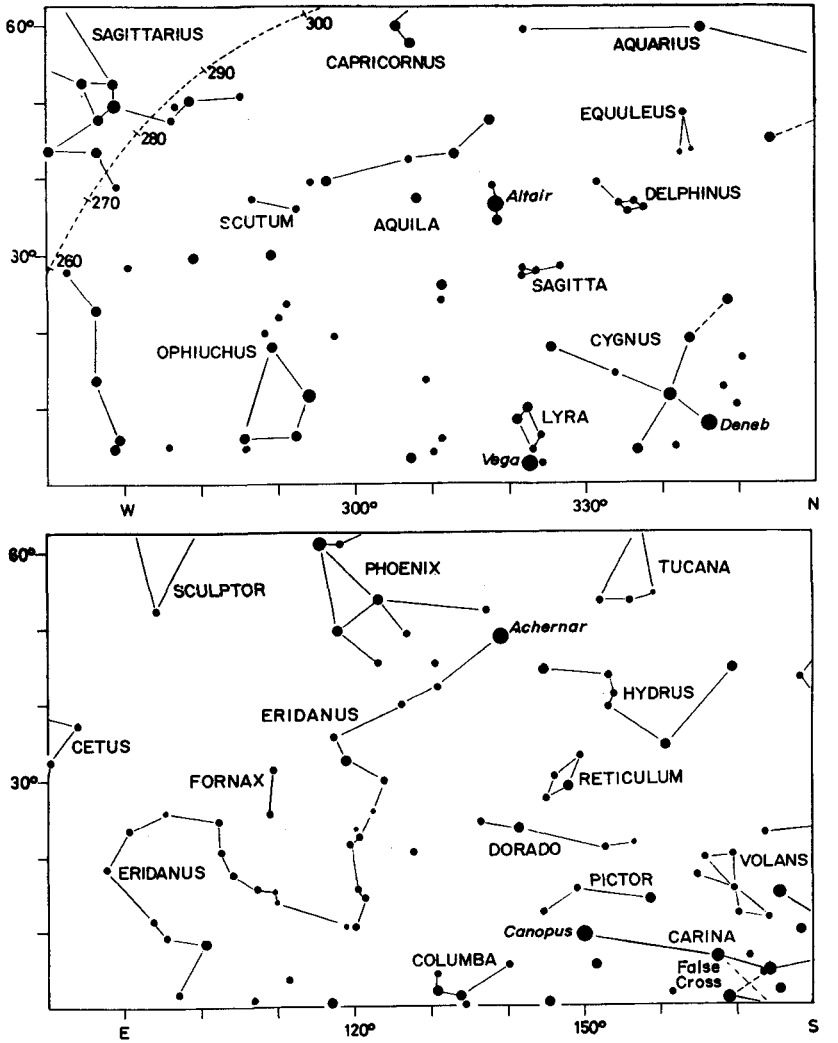


May 6 at 5^h	May 21 at 4^h	**8R**
June 6 at 3^h	June 21 at 2^h	
July 6 at 1^h	July 21 at midnight	
August 6 at 23^h	August 21 at 22^h	
September 6 at 21^h	September 21 at 20^h	

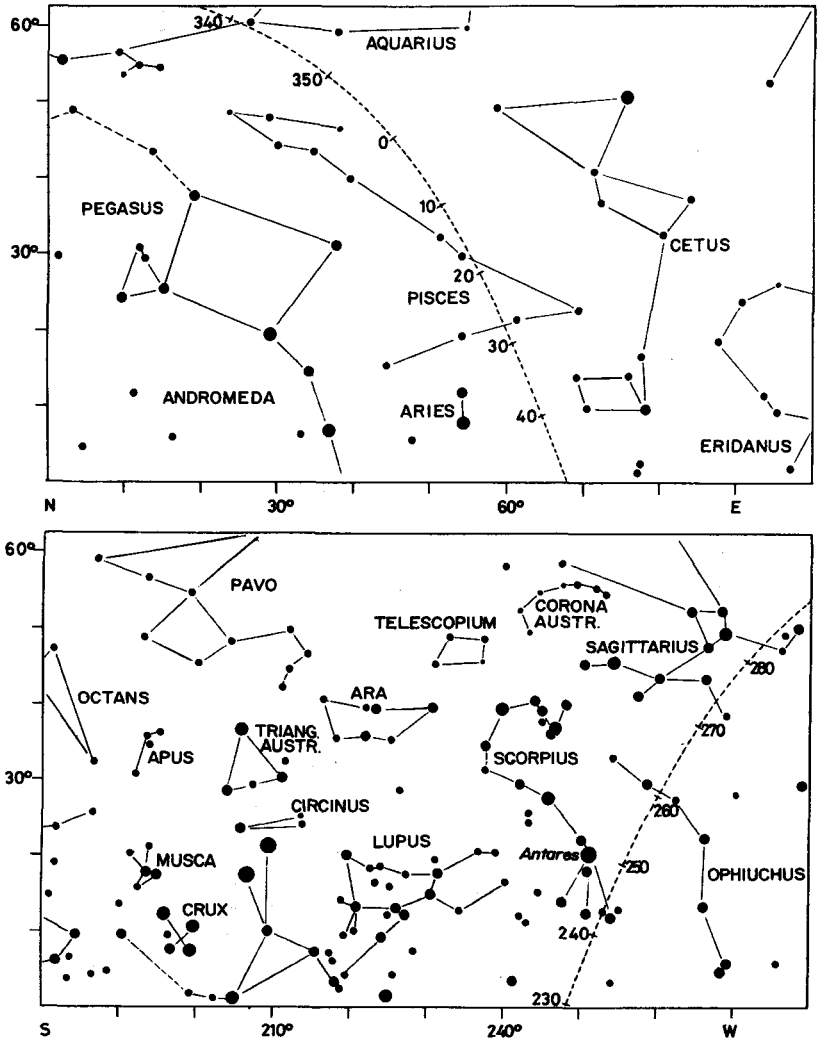


9L

June 6 at 5^h	June 21 at 4^h
July 6 at 3^h	July 21 at 2h
August 6 at 1^h	August 21 at midnight
September 6 at 23^h	September 21 at 22^h
October 6 at 21^h	October 21 at 20^h

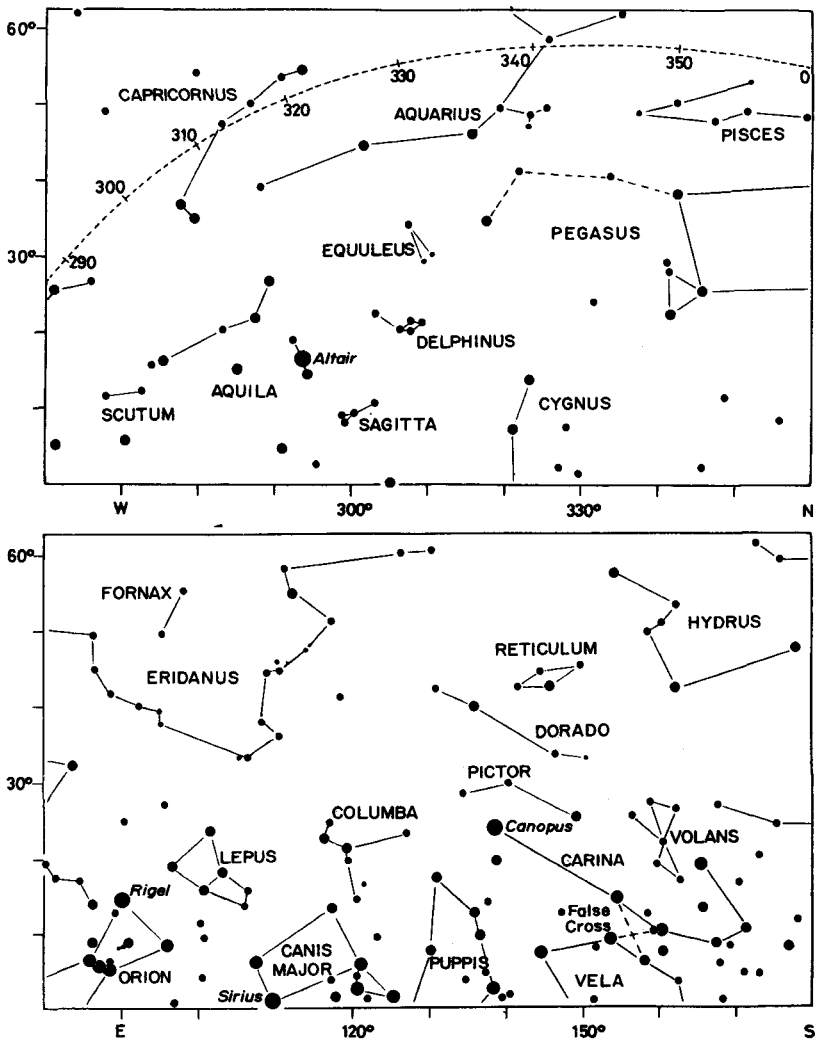


June 6 at 5^h	June 21 at 4^h	**9R**
July 6 at 3^h	July 21 at 2h	
August 6 at 1^h	August 21 at midnight	
September 6 at 23^h	September 21 at 22^h	
October 6 at 21^h	October 21 at 20^h	

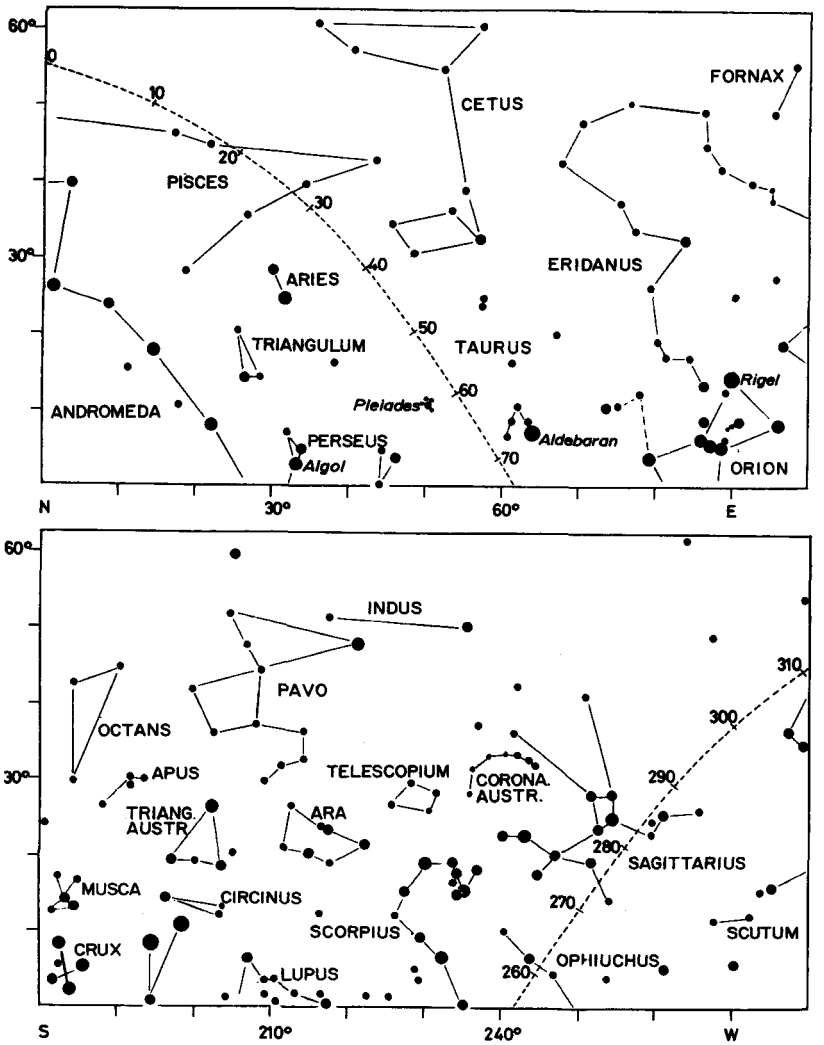


10L

July 6 at 5^h	July 21 at 4^h
August 6 at 3^h	August 21 at 2^h
September 6 at 1^h	September 21 at midnight
October 6 at 23^h	October 21 at 22^h
November 6 at 21^h	November 21 at 20^h

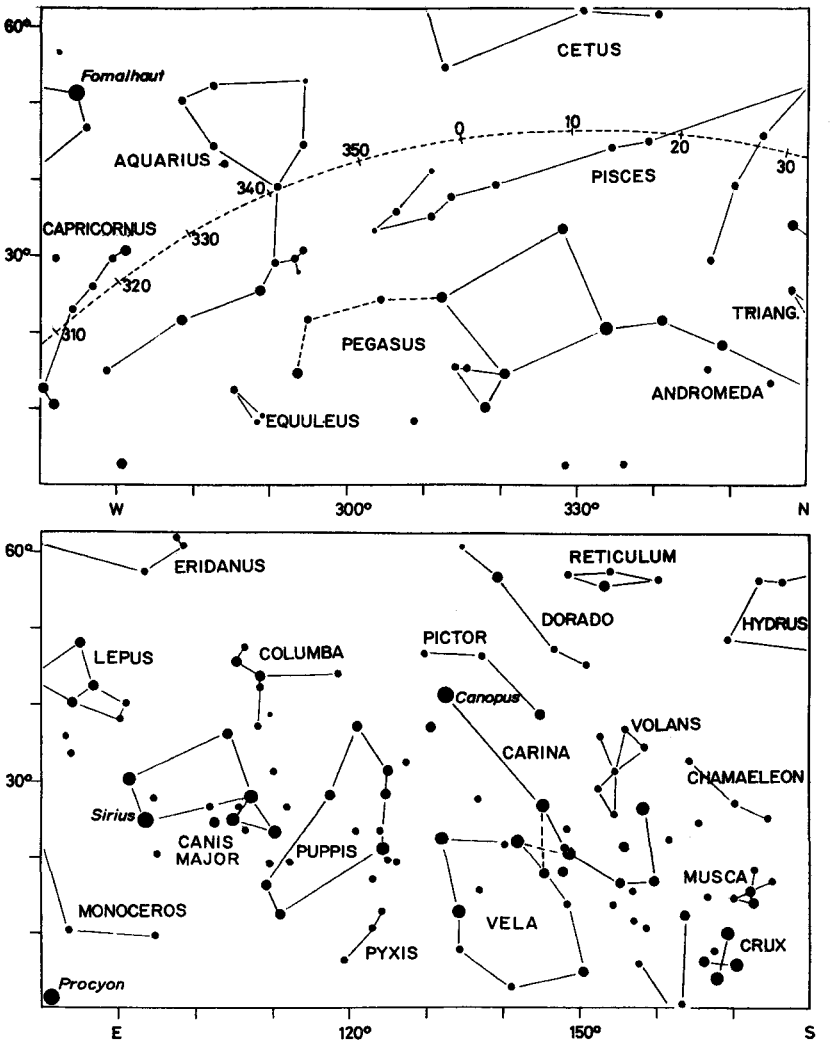


July 6 at 5^h	July 21 at 4^h	**10R**
August 6 at 3^h	August 21 at 2^h	
September 6 at 1^h	September 21 at midnight	
October 6 at 23^h	October 21 at 22^h	
November 6 at 21^h	November 21 at 20^h	



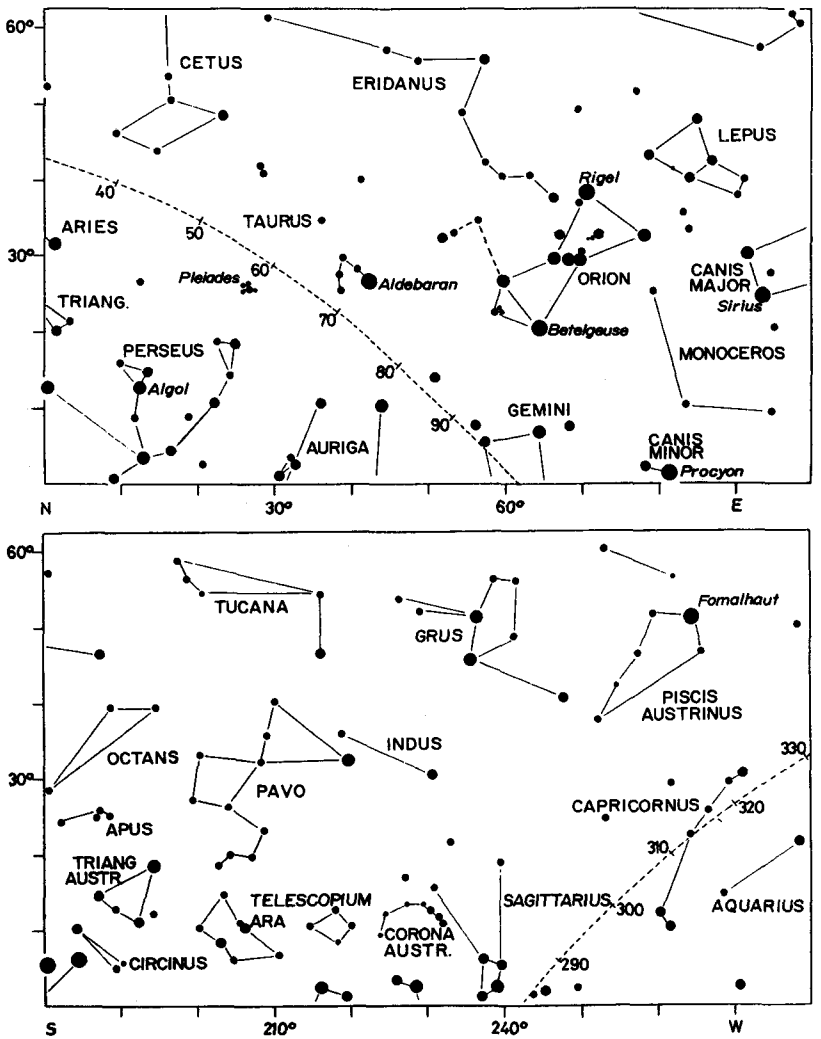
11L

August 6 at	5^h	August 21 at	4^h
September 6 at	3^h	September 21 at	2^h
October 6 at	1^h	October 21 at	midnight
November 6 at	23^h	November 21 at	22^h
December 6 at	21^h	December 21 at	20^h



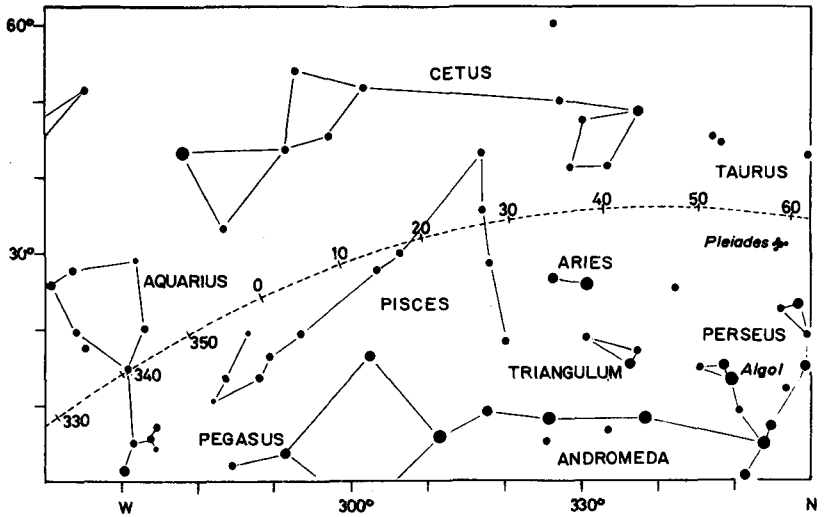
August 6 at	5^h	August 21 at	4^h
September 6 at	3^h	September 21 at	2^h
October 6 at	1^h	October 21 at	midnight
November 6 at	23^h	November 21 at	22^h
December 6 at	21^h	December 21 at	20^h

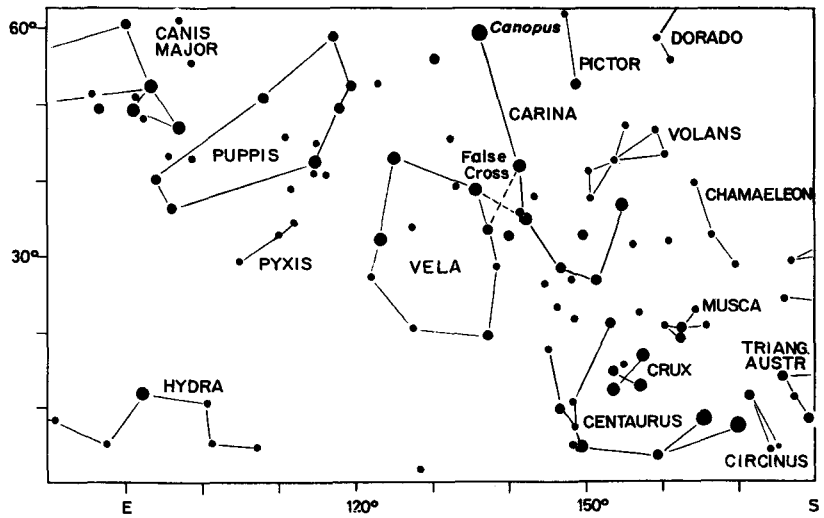
11R



12L

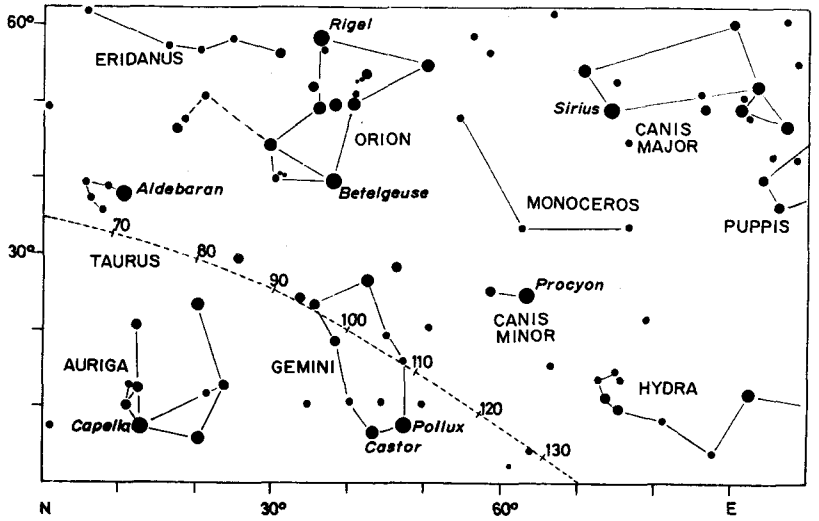
September 6 at	5^h	September 21 at	4^h
October 6 at	3^h	October 21 at	2^h
November 6 at	1^h	November 21 at	midnight
December 6 at	23^h	December 21 at	22^h
January 6 at	21^h	January 21 at	20^h

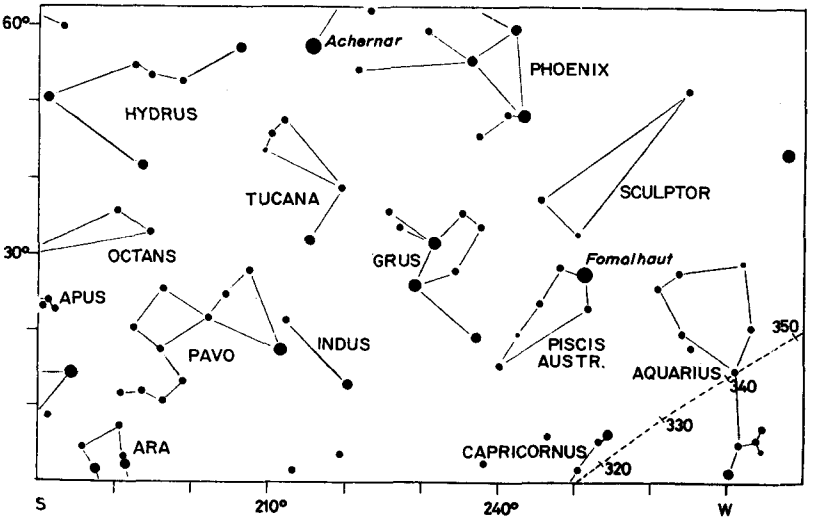


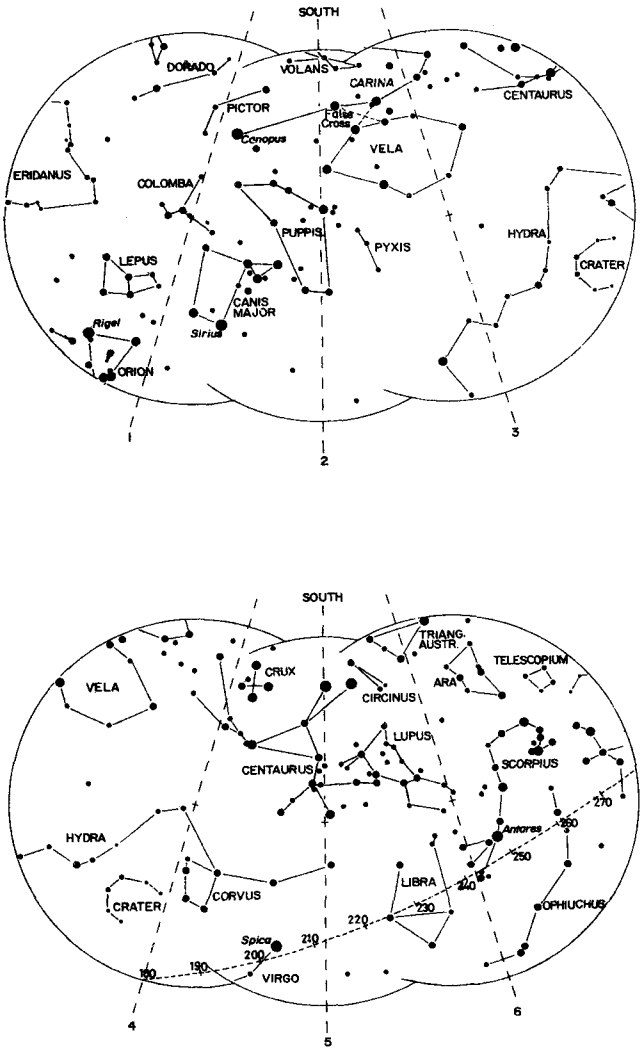


September 6 at 5^h	September 21 at 4^h
October 6 at 3^h	October 21 at 2^h
November 6 at 1^h	November 21 at midnight
December 6 at 23^h	December 21 at 22^h
January 6 at 21^h	January 21 at 20^h

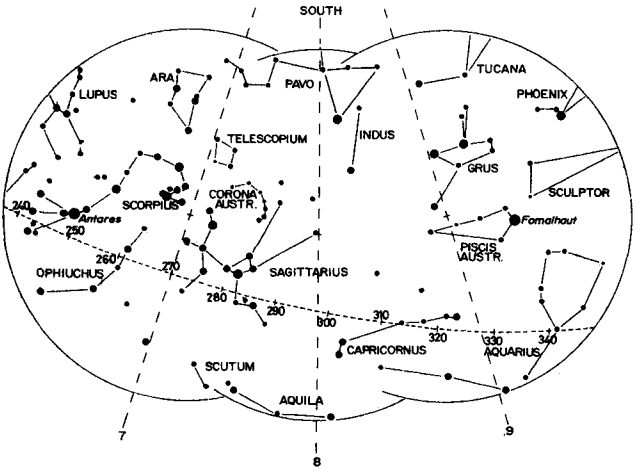
12R

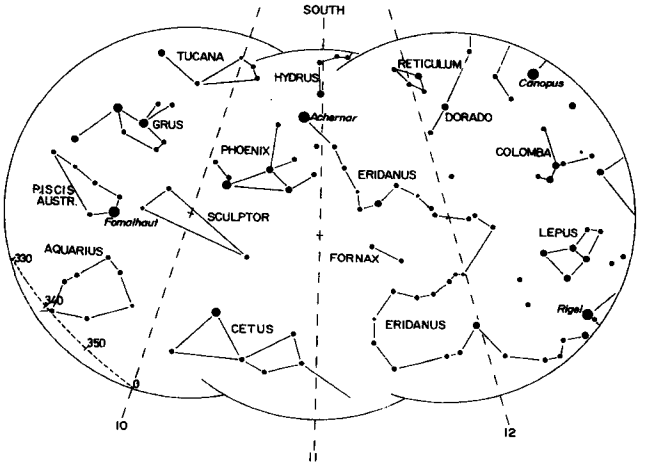






Southern Hemisphere Overhead Stars





Southern Hemisphere Overhead Stars

The Planets and the Ecliptic

The paths of the planets about the Sun all lie close to the plane of the ecliptic, which is marked for us in the sky by the apparent path of the Sun among the stars, and is shown on the star charts by a broken line. The Moon and planets will always be found close to this line, never departing from it by more than about 7 degrees. Thus the planets are most favourably placed for observation when the ecliptic is well displayed, and this means that it should be as high in the sky as possible. This avoids the difficulty of finding a clear horizon, and also overcomes the problem of atmospheric absorption, which greatly reduces the light of the stars. Thus a star at an altitude of 10 degrees suffers a loss of 60 per cent of its light, which corresponds to a whole magnitude; at an altitude of only 4 degrees, the loss may amount to two magnitudes.

The position of the ecliptic in the sky is therefore of great importance, and since it is tilted at about 23½ degrees to the equator, it is only at certain times of the day or year that it is displayed to the best advantage. It will be realized that the Sun (and therefore the ecliptic) is at its highest in the sky at noon in midsummer, and at its lowest at noon in midwinter. Allowing for the daily motion of the sky, these times lead to the fact that the ecliptic is highest at midnight in winter, at sunset in the spring, at noon in summer and at sunrise in the autumn. Hence these are the best times to see the planets. Thus, if Venus is an evening star, in the western sky after sunset, it will be seen to best advantage if this occurs in the spring, when the ecliptic is high in the sky and slopes down steeply to the north-west. This means that the planet is not only higher in the sky, but will remain for a much longer period above the horizon. For

similar reasons, a morning star will be seen at its best on autumn mornings before sunrise, when the ecliptic is high in the east. The outer planets, which can come to opposition (i.e. opposite the Sun), are best seen when opposition occurs in the winter months, when the ecliptic is high in the sky at midnight.

The seasons are reversed in the Southern Hemisphere, spring beginning at the September Equinox, when the Sun crosses the Equator on its way south, summer begins at the December Solstice, when the Sun is highest in the southern sky, and so on. Thus, the times when the ecliptic is highest in the sky, and therefore best placed for observing the planets, may be summarised as follows:

	Midnight	*Sunrise*	*Noon*	*Sunset*
Northern lats.	December	September	June	March
Southern lats.	June	March	December	September

In addition to the daily rotation of the celestial sphere from east to west, the planets have a motion of their own among the stars. The apparent movement is generally *direct,* i.e. to the east, in the direction of increasing longitude, but for a certain period (which depends on the distance of the planet) this apparent motion is reversed. With the outer planets this *retrograde* motion occurs about the time of opposition. Owing to the different inclination of the orbits of these planets, the actual effect is to cause the apparent path to form a loop, or sometimes an S-shaped curve. The same effect is present in the motion of the inferior planets, Mercury and Venus, but it is not so obvious, since it always occurs at the time of inferior conjunction.

The inferior planets, Mercury and Venus, move in smaller orbits than that of the Earth, and so are always seen near the Sun. They are most obvious at the times of greatest angular distance from the Sun (greatest elongation), which may reach 28 degrees for Mercury, or 47 degrees for Venus. They are then seen as evening stars in the western sky after sunset (at eastern elongations) or as morning stars in the eastern sky before sunrise (at western elongations). The succession of phenomena, conjunctions and elongations, always follows the

same order, but the intervals between them are not equal. Thus, if either planet is moving round the far side of its orbit its motion will be to the east, in the same direction in which the Sun appears to be moving. It therefore takes much longer for the planet to overtake the Sun—that is, to come to superior conjunction—than it does when moving round to inferior conjunction, between Sun and Earth. The intervals given in the following table are average values; they remain fairly constant in the case of Venus, which travels in an almost circular orbit. In the case of Mercury, however, conditions vary widely because of the great eccentricity and inclination of the planet's orbit.

		Mercury	*Venus*
Inferior conj.	to Elongation West	22 days	72 days
Elongation West	to Superior conj.	36 days	220 days
Superior conj.	to Elongation East	36 days	220 days
Elongation East	to Inferior conj.	22 days	72 days

The greatest brilliancy of Venus always occurs about 36 days before or after inferior conjunction. This will be about a month *after* greatest eastern elongation (as an evening star), or a month *before* greatest western elongation (as a morning star). No such rule can be given for Mercury, because its distance from the Earth and the Sun can vary over a wide range.

Mercury is not likely to be seen unless a clear horizon is available. It is seldom seen as much as 10 degrees above the horizon in the twilight sky in northern latitudes, but this figure is often exceeded in the Southern Hemisphere. This favourable condition arises because the maximum elongation of 28 degrees can occur only when the planet is at aphelion (farthest from the Sun), and this point lies well south of the Equator. Northern observers must be content with smaller elongations, which may be as little as 18 degrees at perihelion. In general, it may be said that the most favourable times for seeing Mercury as an evening star will be in spring, some days before greatest eastern elongation; in autumn, it may be seen as a morning star some days after greatest western elongation.

Venus is the brightest of the planets, and may be seen on occasions in broad daylight. Like Mercury, it is alternately a morning and an evening star, and will be highest in the sky when it is a morning star in autumn, or an evening star in spring. The phenomena of Venus given in the table above can occur only in the months of January, April, June, August and November, and it will be realized that they do not all lead to favourable apparitions of the planet. In fact, Venus is to be seen at its best as an evening star in northern latitudes when eastern elongation occurs in June. The planet is then well north of the Sun in the preceding spring months, and is a brilliant object in the evening sky over a long period. In the Southern Hemisphere a November elongation is best. For similar reasons, Venus gives a prolonged display as a morning star in the months following western elongation in November (in northern latitudes) or in June (in the Southern Hemisphere).

The superior planets, which travel in orbits larger than that of the Earth, differ from Mercury and Venus in that they can be seen opposite the Sun in the sky. The superior planets are morning stars after conjunction with the Sun, rising earlier each day until they come to opposition. They will then be nearest to the Earth (and therefore at their brightest), and will be on the meridian at midnight, due south in northern latitudes, but due north in the Southern Hemisphere. After opposition they are evening stars, setting earlier each evening until they set in the west with the Sun at the next conjunction. The change in brightness about the time of opposition is most noticeable in the case of Mars, whose distance from the Earth can vary considerably and rapidly. The other superior planets are at such great distances that there is very little change in brightness from one opposition to another. The effect of altitude is, however, of some importance, for at a December opposition in northern latitudes the planet will be among the stars of Taurus or Gemini, and can then be at an altitude of more than 60 degrees in southern England. At a summer opposition, when the planet is in Sagittarius, it may only rise to about 15 degrees above the southern horizon, and so makes a

less impressive appearance. In the Southern Hemisphere, the reverse conditions apply; a June opposition being the best, with the planet in Sagittarius at an altitude which can reach 78 degrees above the northern horizon.

Mars, whose orbit is appreciably eccentric, comes nearest to the Earth at an opposition at the end of August. It may then be brighter even than Jupiter, but rather low in the sky in Aquarius for northern observers, though very well placed for those in southern latitudes. These favourable oppositions occur every fifteen or seventeen years (1924, 1941, 1956, 1971) but in the Northern Hemisphere the planet is probably better seen at an opposition in the autumn or winter months, when it is higher in the sky. Oppositions of Mars occur at an average interval of 780 days, and during this time the planet makes a complete circuit of the sky.

Jupiter is always a bright planet, and comes to opposition a month later each year, having moved, roughly speaking, from one Zodiacal constellation to the next.

Saturn moves much more slowly than Jupiter, and may remain in the same constellation for several years. The brightness of Saturn depends on the aspect of its rings, as well as on the distance from Earth and Sun. The rings are now closing, and are inclined towards the Earth and Sun at quite a small angle. They will be seen edge-on in 1979.

Uranus, Neptune, and *Pluto* are hardly likely to attract the attention of observers without adequate instruments, but some notes on their present positions in the sky will be found in the April, May and June Notes.

Phases of the Moon 1978

New Moon	d	h	m	*First Quarter*	d	h	m	*Full Moon*	d	h	m	*Last Quarter*	d	h	m
												Jan.	2	12	07
Jan.	9	04	00	Jan.	16	03	03	Jan.	24	07	55	Jan.	31	23	51
Feb.	7	14	54	Feb.	14	22	11	Feb.	23	01	26	Mar.	2	08	34
Mar.	9	02	36	Mar.	16	18	21	Mar.	24	16	20	Mar.	31	15	11
Apr.	7	15	15	Apr.	15	13	56	Apr.	23	04	11	Apr.	29	21	02
May	7	04	47	May	15	07	39	May	22	13	17	May	29	03	30
June	5	19	01	June	13	22	44	June	20	20	30	June	27	11	44
July	5	09	50	July	13	10	49	July	20	03	05	July	26	22	31
Aug.	4	01	01	Aug.	11	20	06	Aug.	18	10	14	Aug.	25	12	18
Sept.	2	16	09	Sept.	10	03	20	Sept.	16	19	01	Sept.	24	05	07
Oct.	2	06	41	Oct.	9	09	38	Oct.	16	06	09	Oct.	24	00	34
Oct.	31	20	06	Nov.	7	16	18	Nov.	14	20	00	Nov.	22	21	24
Nov.	30	08	19	Dec.	7	00	34	Dec.	14	12	31	Dec.	22	17	41
Dec.	29	19	36	Jan.	5	11	15	Jan.	13	07	09	Jan.	21	11	23

All times are G.M.T.

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The Planets in 1978

DATE		*Venus*	*Mars*	*Jupiter*	*Saturn*	*Uranus*	*Neptune*
January	6	281°	129°	89°	151°	226°	257°
	21	301	123	88	150	226	258
February	6	321	117	86	149	226	258
	21	340	114	86	147	227	258
March	6	356	113	86	146	226	258
	21	15	115	87	145	226	258
April	6	34	119	89	145	226	258
	21	52	124	91	144	225	258
May	6	70	131	94	144	224	258
	21	89	138	97	145	224	258
June	6	108	146	100	146	223	257
	21	126	154	103	147	223	257
July	6	144	163	107	148	223	256
	21	161	172	110	150	222	256
August	6	178	181	114	152	223	256
	21	193	191	117	154	223	256
September	6	208	201	120	156	223	256
	21	220	211	123	158	224	256
October	6	228	221	125	159	225	256
	21	231	231	127	161	226	256
November	6	225	243	129	163	227	257
	21	218	254	129	164	228	257
December	6	219	265	129	164	228	258
	21	227	276	128	165	229	259
Conjunction:		Jan. 22	——	July 10	Aug. 27	Nov. 9	Dec. 10
Opposition:		——	Jan. 22	——	Feb. 16	May 5	June 8

Mercury moves so quickly among the stars that it is not possible to indicate its position on the star charts at a convenient interval. The monthly notes must be consulted for the best times at which the planet may be seen.

The positions of the other planets are given in the table on the previous page. This gives the apparent longitudes on dates which correspond to those of the star charts, and the position of the planet may at once be found near the ecliptic at the given longitude.

Examples:

(1) *Where may the planet Mars be found at the end of January?*
The table opposite gives the longitude of Mars at this time as 120 degrees. In northern latitudes Chart 11R is appropriate, and shows Mars to be rising at about 18^h, to the north of east below the Twins, Castor and Pollux. Southern observers will use Chart 12R (southern) which shows Mars to be rising about 20^h local time.

(2) *What is the bright planet seen by an observer in Sydney, N.S.W., to be setting in the north-west at about 20^h at the end of April?*
Southern Chart 3L applies, and the longitude of the planet is seen to be about 90 degrees. The table opposite identifies the planet as Jupiter.

(3) *The Monthly Notes for May state that Mars is approaching Saturn. Where may these planets be found on the night of May 20?*
The table opposite gives the longitude of Saturn as 145 degrees, while Mars is at 138 degrees. Observers in northern latitudes may use Charts 4R or 5R, showing Saturn to be a few degrees to the west of Regulus, with Mars still farther west. Both planets set about midnight. Conditions are more favourable in the Southern Hemisphere, and Chart 5L (southern) shows these planets to be setting to the north of west at about 22^h local time.

Events of 1978

ECLIPSES

In 1978 there will be four eclipses, two of the Sun and two of the Moon.

24 March—a total eclipse of the Moon, visible in Australia, Asia, Africa, and Europe.

7 April—a partial eclipse of the Sun, visible in South America and Southern Africa.

16 September—a total eclipse of the Moon, visible in Australia, Asia, Africa, and Europe.

2 October—a partial eclipse of the Sun, visible in northern Europe, Asia, and the Arctic regions.

THE PLANETS

Mercury may best be seen in northern latitudes as an evening star at greatest eastern elongation on 24 March, and as a morning star at western elongation on 4 September.

Venus is in superior conjunction on 22 January, and will be an evening star for the greater part of the year. It is at greatest eastern elongation on 29 August, and is at greatest brilliancy on 3 October. After inferior conjunction on 7 November it will be a morning star, reaching greatest brilliancy on 14 December.

Mars will be at opposition in Cancer on 22 January.

Jupiter is an evening star for the first half of the year, and after conjunction on 10 July will be a morning star. There is no opposition of Jupiter in 1978.

Saturn is at opposition in Leo on 16 February.

Uranus will be at opposition in Libra on 5 May.

Neptune remains in Ophiuchus and will be at opposition on 8 June.

Pluto will be at opposition on 5 April in Virgo.

Vesta will reach magnitude +5.5 at opposition on 5 June, but is then low in the sky in Ophiuchus.

MONTHLY NOTES, 1978

January

New Moon: 9 January *Full Moon:* 24 January

Earth is at perihelion (nearest to the Sun) on 1 January at a distance of 91.4 million miles (147.1 million km).

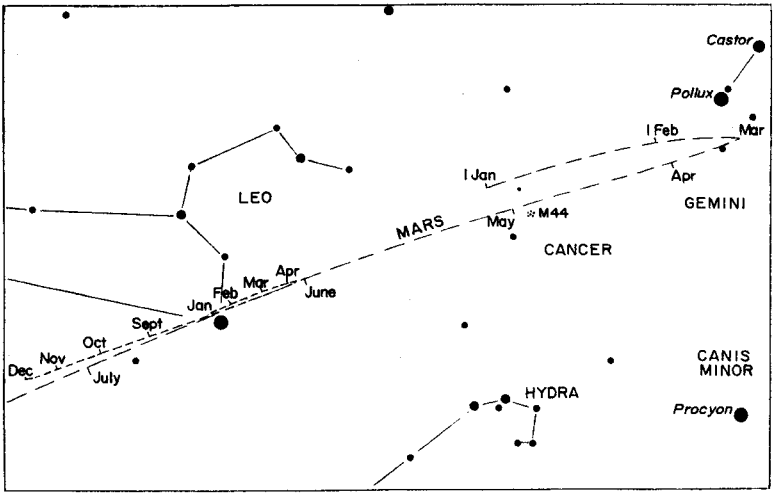
Mercury is a morning star, coming to greatest western elongation on 11 January (23 degrees). It should then be visible above the eastern horizon just before sunrise, and is brighter after greatest elongation. The planet is well south of the Equator, and will be better placed for observers in the Southern Hemisphere.

Venus is in superior conjunction on 22 January, and will not be visible during the month. After conjunction, the planet will slowly emerge as an evening star.

Mars is at opposition on 22 January, reaching magnitude −1.1. The planet will be at its closest to the Earth on the 19th, at a distance of 60.7 million miles (97.7 million km). Mars is moving retrograde in Cancer, and passes north of the star Gamma Cancri and the star cluster Præsepe (M44). This is not a particularly favourable opposition, and it may be compared with that of 1971, when the distance was only 35 million miles, and the magnitude reached −2.6.

Jupiter was at opposition in December last, and is still visible for most of the night. It will be seen on the borders of Gemini and Taurus, moving retrograde to the north of Orion. Magnitude −2.3 to −2.2. (See diagram in November notes.)

Saturn rises in mid-evening and will be found in Leo to the east of Regulus. The planet is moving retrograde, and will pass about a degree north of Regulus on 20 January. This is the second of three conjunctions with Regulus, caused by the loop in Saturn's path. The first was in November last, and the third will be in July. Saturn grows brighter during the month as it approaches opposition. (Magnitude +0.6 to +0.4.)



Mars and Saturn 1978

February

New Moon: 7 February *Full Moon:* 23 February

Mercury is in superior conjunction on 27th February, and will not be seen during the month.

Venus is now theoretically an evening star, but is too close to the Sun to be seen. Venus is well south of the Equator, but is moving north, and during the spring months it will be more readily observable in northern latitudes.

Mars is an evening star, still moving retrograde and passing into Gemini at the beginning of the month. Mars will be 3 degrees south of Pollux on 17 February. During the month the brightness of the planet diminishes rapidly (magnitude −1.0 to −0.3).

Jupiter reaches a stationary point on 20 February in Taurus, to the north of Orion, and after this date it resumes its direct motion. The planet sets to the north of west just before dawn in northern latitudes, but at midnight for southern observers. Magnitude −2.2 to −2.0.

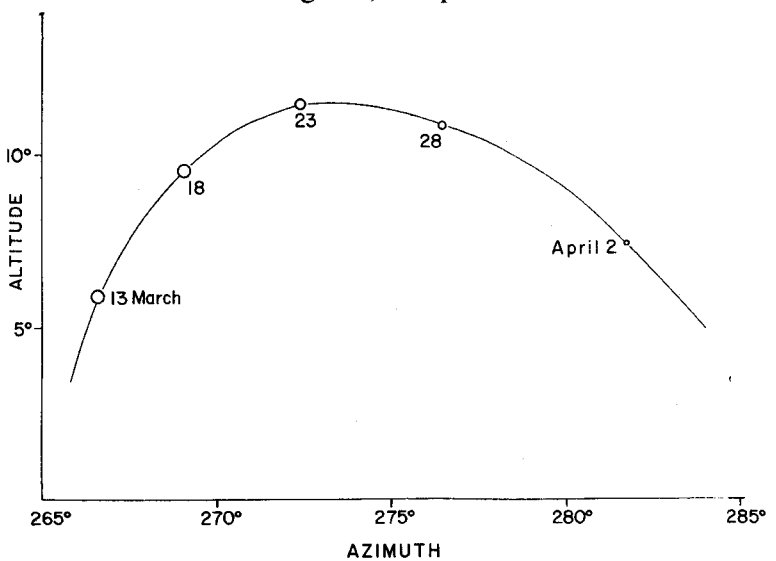
Saturn is at opposition on 16 February at a distance of 766 million miles (1,232 million km). It will then be in Leo, about 3 degrees west of Regulus (see diagram in January notes). The rings are tilted at an angle of about 11 degrees, and the south side is presented to the Earth. The planet reaches magnitude +0.3 at opposition, but it can be much brighter than this when the rings are open more widely.

March

Summer Time in Great Britain and Northern Ireland commences on 19 March.

New Moon: 9 March *Full Moon:* 24 March
Equinox: 20 March

Mercury is at greatest eastern elongation on 24 March and may then be seen as an evening star, well placed for observers in the



Mercury–March, 1978

Northern Hemisphere. The diagram above shows the changes in altitude and azimuth (true bearing from the north through

east, south and west) of Mercury on successive evenings when the Sun is 6 degrees below the horizon in latitude 52 degrees north (this is about 35 minutes after sunset). The changes in brightness are roughly indicated by the size of the circles, and it will be seen that Mercury is brightest *before* the date of eastern elongation. Venus is in the same part of the sky, but is much brighter and sets earlier than Mercury.

Venus now begins to appear as an evening star to observers in northern latitudes, setting more than an hour after the Sun at the end of March. The planet crosses the equator on its way north in mid-March. Magnitude −3.4.

Mars reaches a stationary point on 2 March in Gemini (see diagram in January notes), and then moves direct, passing 4 degrees south of Pollux again on the 17th. The planet is growing rapidly fainter (magnitude −0.3 to +0.5) as its distance increases. In northern latitudes Mars will be visible until dawn, but in the Southern Hemisphere it sets shortly after midnight.

Jupiter is an evening star, and in the Northern Hemisphere will be seen in the south at sunset, setting an hour or so after midnight. In southern latitudes the planet is much lower in the northern sky, and sets before midnight. Jupiter is now moving direct in Taurus, near the border with Gemini. (Magnitude −2.0 to −1.7.)

Saturn is still visible for most of the night to observers north of the Equator, but in southern latitudes it sets in the early morning hours. The planet is moving retrograde in Leo, to the west of Regulus and it forms a notable group with the Sickle of Leo. Saturn is much brighter than Regulus (magnitude +1.3) but loses something of its brightness as its distance increases (magnitude +0.3 to +0.5).

A total eclipse of the Moon on 24 March will be visible in Australia and New Zealand, and the end of the eclipse will be visible in the British Isles. See note on page 100.

April

New Moon: 7 April *Full Moon:* 23 April

Mercury is in inferior conjunction on 11 April and will not be visible during the month.

Venus is now north of the Equator and will be seen in the western sky in northern latitudes for about two hours after sunset. In the Southern Hemisphere it begins to appear as an evening star, but even at the end of April it sets only about an hour after the Sun. Magnitude −3.4.

Mars is an evening star, and moves direct into Cancer at the beginning of the month. At the end of April it passes between the two stars Gamma and Delta Cancri, and north of the star cluster Præsepe (M44). Northern observers will see the planet in the south at sunset, and it will be visible until dawn. In southern latitudes, the planet sets at midnight at the beginning of the month. Magnitude +0.5 to +1.0.

Jupiter moves direct into Gemini and may still be seen in the evening sky. In the Northern Hemisphere, it sets at midnight, but much earlier for southern observers. (Magnitude −1.7 to −1.6.)

Saturn reaches a stationary point on 25 April a few degrees to the west of Regulus. After this date the planet will move eastwards again, towards Regulus. Saturn will still be visible for most of the night in northern latitudes, but sets shortly after midnight in the Southern Hemisphere. By the end of April the magnitude will have fallen to +0.6.

Pluto is at opposition on 5 April in Virgo, near the northern part of that constellation. The magnitude at opposition is only +14, the distance from the Earth being 2,735 million miles (4,400 million km). This is very little more than the opposition distance of Neptune (see June notes).

A partial eclipse of the Sun on 7 April will be visible in parts of South Africa (see note on page 100).

May

New Moon: 7 May *Full Moon:* 22 May

Mercury is at greatest western elongation on 9 May (26 degrees) and will then be a morning star. It is too low to be well seen in northern latitudes, but is well placed for observers in the Southern Hemisphere. At 35 degrees south, Mercury rises about two hours before the Sun on the 10th, and will be seen above the eastern horizon. The planet was at aphelion on 30 April, and is not very bright—magnitude +0.6 on the 12th, but brighter after this date.

Venus is now at its farthest point north of the Equator, and well placed for observation in the Northern Hemisphere. At 52 degrees north it sets to the north of west more than two hours after the Sun. Venus will be seen close to Jupiter on the evening of 28 May, and the actual conjunction (Venus 1.6 degrees north of Jupiter) at 29 May 02h G.M.T., should be worth observing in North America. Magnitude −3.4.

Mars is an evening star and moves into Leo towards the end of the month. The planet will be seen to have a rapid direct movement towards Saturn, and the changes in position as it overhauls the brighter planet will be worth observing. Magnitude of Mars +1.0 to +1.4. In southern latitudes Mars sets before midnight, but northern observers have about two hours longer to look for the planet.

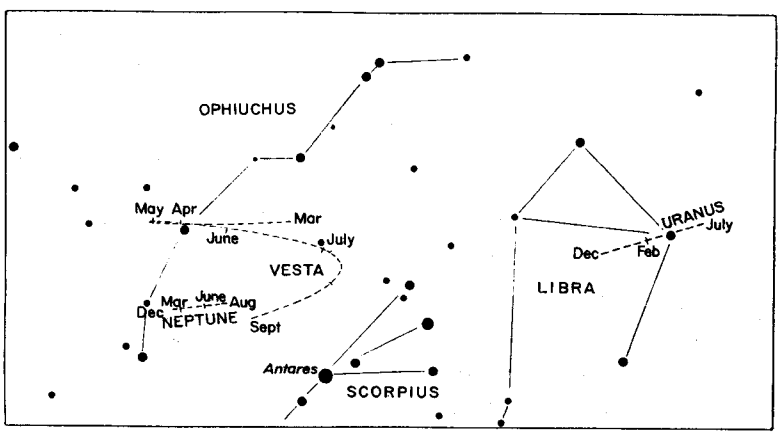
Jupiter is now in the western part of Gemini, giving an unfamiliar appearance to the well-known group. The planet is moving direct, but will be passed by the more rapidly moving

Venus on 29 May (see note above). The two bright planets will be seen to set together to the north of west about two hours after sunset.

Saturn may be seen in the evening sky until shortly after midnight in northern countries, but in the Southern Hemisphere it sets at midnight in early May and well before this by the end of the month. The planet is moving slowly eastwards towards Regulus, and loses a little more of its brightness (magnitude +0.6 to +0.8).

Uranus is at opposition on 5 May in Libra, very close to the third magnitude star Alpha Libræ (Zuben-el-Genubi). The planet moves very slowly and it should be possible to find it close to the star at the end of April and in early May. The magnitude at opposition is +5.7 and the distance 1,638 million miles (2,636 million km). Uranus should be visible to the naked eye at this time, but a small telescope will show it as a greenish disk.

Vesta comes to opposition in June, but it should be possible to find this bright minor planet during May, when it is brighter than the sixth magnitude.



Uranus, Neptune and Vesta, 1978

June

New Moon: 5 June *Full Moon:* 20 June

Solstice: 21 June

Mercury is in superior conjunction on 14 June and will not be visible.

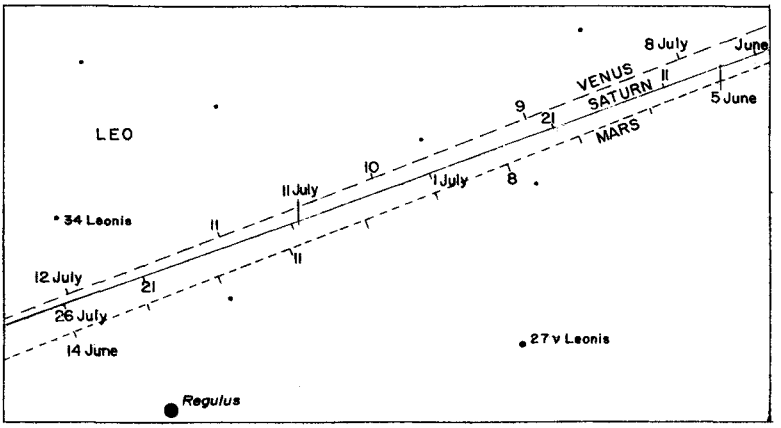
Venus now begins to move south, and this causes considerable changes in the visibility of the planet north and south of the Equator. In the north, Venus begins to set earlier each evening, but is still well seen in the evening sky, setting to the north of west more than two hours after the Sun. In the south, Venus sets later each evening, and by the end of the month is visible for nearly three hours after sunset. Venus begins to grow brighter as its distance decreases (magnitude -3.4 to -3.5).

Mars is moving direct in Leo, and at midnight on 5 June it passes only 0.1 degrees south of Saturn (see diagram below). At this time the motion of Mars is about eight times as great as that of Saturn, and the rapid change of position should be quite noticeable. Mars passes less than a degree north of Regulus on 12 June. In northern latitudes the planet sets at midnight at the beginning of the month, but in the Southern Hemisphere it sets in mid-evening. Magnitude +1.4 to +1.6.

Jupiter is now approaching conjunction and sets shortly after sunset. The planet continues to move direct through Gemini, and although the magnitude is now only -1.4, it is still brighter than any of the stars in this group.

Saturn is still in the western part of Leo, and is drawing close to

Regulus. The conjunction of Saturn with Mars on 5 June is mentioned above, but the diagram in the January notes is on too small a scale to allow this to be shown. The diagram below is on ten times the scale, and shows the paths of Mars, Saturn and Venus, and the occurrence of the two conjunctions. For northern observers Saturn and Mars will set at midnight in early June, but about two hours earlier in southern latitudes. Saturn is the brighter of the two planets (magnitude +0.8).



Conjunctions of Saturn with Mars and Venus

Neptune is at opposition on 8 June at a distance of 2,720 million miles (4,380 million km). The planet is then actually in the constellation Ophiuchus, but is not visible to the naked eye (magnitude +7.7). The position of Neptune at this time is shown in the diagram in the May notes.

Vesta is also in Ophiuchus and comes to opposition on 5 June. This is a particularly favourable opportunity to look for this minor planet, since it is then at perihelion and reaches magnitude +5.5. See diagram and note on page 85 and the note on page 107.

July

New Moon: 5 July *Full Moon:* 20 July

Earth is at aphelion (farthest from the Sun) on 5 July, when its distance will be 94.5 million miles (152.1 million km).

Mercury is at greatest eastern elongation on 22 July (27 degrees) and is then an evening star, well placed for southern observers, but very low in the sky in northern latitudes. The planet is at aphelion on 27 July and is not very bright, but at 35 degrees south it will best be seen in the first half of the month, setting in the west well over an hour after sunset.

Venus continues to move south and become a more prominent object in the evening sky for southern observers. In northern countries it sets less than two hours after the Sun. Magnitude −3.5 to −3.7. Venus passes very close to Saturn on 10 July, but the actual conjunction takes place at 12h G.M.T. and is not likely to be seen. The rapid motion of Venus on succeeding nights is shown in the diagram in the June notes.

Mars is an evening star, setting in the late evening, and at the end of July it passes into Virgo. Magnitude +1.6 to +1.7.

Jupiter is in conjunction with the Sun on 10 July and then begins to appear as a morning star, rising shortly before sunrise.

Saturn is still visible in the western sky for an hour or two after sunset, moving direct in Leo. The conjunction with Venus on

10 July is mentioned above, and Saturn will pass about a degree north of Regulus on 19 July. (Magnitudes: Saturn +0.9, Regulus +1.3)

August

New Moon: 4 August *Full Moon:* 18 August

Mercury is in inferior conjunction on 18 August, and will not be visible until the last few days of the month, when it begins to appear as a morning star.

Venus is at greatest eastern elongation (46 degrees) on 29 August, but it is then south of the Equator and not well placed for northern observers who will only see the planet in the evening sky for about an hour after sunset. In the Southern Hemisphere, it can be seen for more than three hours after the Sun has set, and will be well displayed in a dark sky. Venus passes rather more than a degree south of Mars on 14 August. The planet continues to brighten as it draws nearer to the Earth (magnitude –3.7 to –4.0).

Mars is moving south in Virgo, and crosses the Equator in early August. The planet is now a difficult object for northern observers, setting only about an hour after the Sun, but in southern latitudes it continues to be seen until it sets in mid-evening. The crescent moon of 8 August passes very close to the north of Mars and the planet will be occulted to observers in N.E. Australia (see page 101). Mars is in conjunction with Venus on 14 August, but there is a very great contrast between the two planets, Mars now being only of magnitude +1.8.

Jupiter is now a morning star, rising to the north of east in Gemini, more than two hours before the Sun in northern latitudes. In early August it will be seen to the south of the Twins, Castor and Pollux, and at the end of the month it passes

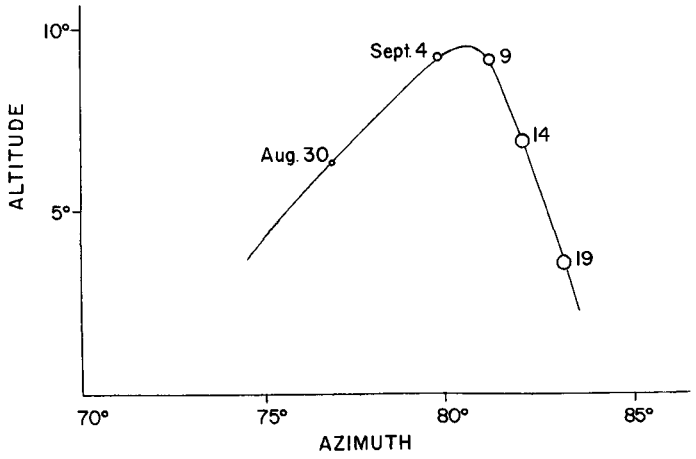
into Cancer. Jupiter grows brighter as it moves out from the Sun, but it is already the brightest star in the morning sky (magnitude –1.5).

Saturn is in conjunction with the Sun on 27 August, and is not visible, but in the Northern Hemisphere, it will quickly move out from the Sun to become a morning star.

September

New Moon: 2 September *Full Moon:* 16 September
Equinox: 23 September

Mercury is at greatest western elongation on 4 September (18 degrees) and may be seen in northern latitudes shortly before sunrise above the horizon to the north of east. The diagram shows the changes in altitude and azimuth of Mercury on successive mornings when the Sun is 6 degrees below the horizon; this is about 35 minutes before sunrise in September. The changes in brightness are roughly indicated by the size of the circles. Mercury is at perihelion on 9 September, and is quite bright *after* the date of elongation. Mercury is in superior conjunction on 30 September.



Mercury–September, 1978

Venus is now a brilliant object in the evening sky in southern latitudes (magnitude −4.0 to −4.3), setting more than three hours after the Sun. It is not likely to be seen in the Northern Hemisphere since it sets shortly after the Sun.

Mars also sets about an hour after the Sun in northern countries, but it is now at its faintest and will be lost in the evening twilight. In southern stations, Mars is still visible as an evening star until mid-evening. The planet is moving direct in Virgo, and passes about 2 degrees north of Spica on 8 September.

Jupiter is now a morning star moving direct in Cancer and very conspicuous in this barren part of the sky (magnitude −1.5 to −1.6). North of the Equator the planet rises about midnight, but much later at southern stations.

Saturn is also a morning star, moving direct in Leo to the south and east of Regulus. At northern stations, the planet emerges quickly from the Sun's rays, and by the end of September it rises more than two hours before the Sun. In the Southern Hemisphere, Saturn rises shortly before sunrise, and is hardly likely to be seen, since it is now only of the first magnitude.

A total eclipse of the Moon occurs on 16 September, the early stages visible in Australia and New Zealand, the final stages in the British Isles. (See note on page 100).

October

Summer Time in Great Britain and Northern Ireland ends on 22 October.

New Moon: 2 and 31 October *Full Moon:* 16 October

Mercury was in superior conjunction at the end of September, and is not likely to be visible until the end of October.

Venus reaches greatest brilliancy (magnitude −4.3) on 3 October and will be a splendid object in the western sky in southern latitudes. The planet moves rapidly towards inferior conjunction, and sets earlier each evening; by the end of October it sets about an hour after the Sun. Venus is now at its farthest point south of the Equator, and it will not be seen in northern latitudes. The planet passes 7 degrees south of Mars on 20 October, and it may be possible to see this conjunction from Australia and New Zealand, although Mars is now quite a faint object.

Mars is not likely to be seen in northern latitudes, but south of the Equator it may still be visible for an hour or two after sunset. The planet moves into Libra at the beginning of October, and passes half a degree south of Alpha Libræ (Zuben-el-Genubi) on the 11th. Mars is overtaken again by Venus on 20 October—a very noticeable contrast in brightness (Mars +1.7, Venus −4.1).

Jupiter is still a morning star in Cancer, but in northern latitudes it will rise before midnight at the end of the month. It will then be close to the fourth magnitude star, Delta Cancri.

Jupiter is growing a little brighter as it comes round towards the Earth (magnitude −1.6 to −1.8).

Saturn is a morning star in Leo, south of the well-known figure of the Lion. In the Northern Hemisphere it rises in the early morning hours in a dark sky, but in the south it will be more difficult to observe, rising little more than an hour before the Sun. Magnitude +1.1.

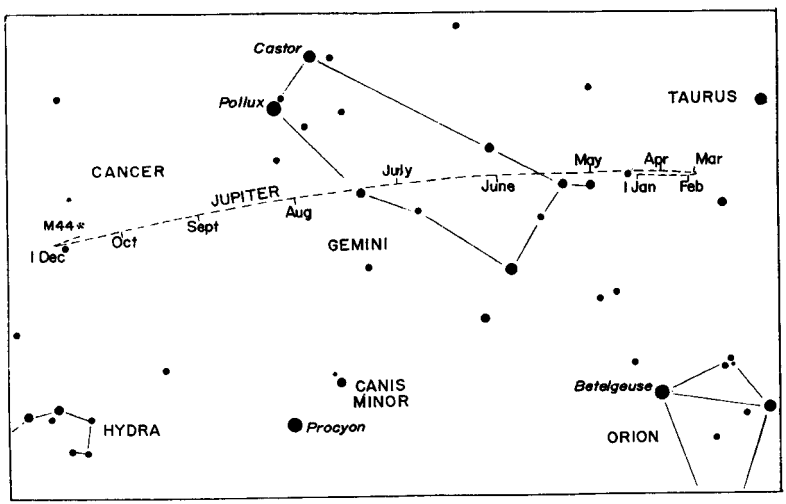
A partial eclipse of the Sun will occur on 2 October, but will not be generally visible. See note on page 100.

November

Full Moon: 14 November *New Moon:* 30 November

Mercury is at greatest eastern elongation on 16 November (23 degrees), and it may be seen in southern latitudes as an evening star after sunset in the south-west. At 35 degrees south on this date, the planet sets nearly two hours after the Sun. Mercury is brighter before eastern elongation.

Venus is in inferior conjunction on 7 November, and after this date it begins to appear quite rapidly as a morning star in the east at sunrise. Conditions are best in the Northern Hemisphere, and here, by the end of November, Venus will rise more



Jupiter, 1978

than two hours before the Sun. It will then be of magnitude −4.2.

Mars is still an evening star, but sets shortly after sunset. The planet moves through Scorpius into Ophiuchus during the month.

Jupiter is in Cancer and reaches a stationary point on 26 November near the star Delta Cancri, having passed very close to the north of this star on 4 November. In northern latitudes Jupiter rises in the late evening to the north of east. For southern observers the rising is delayed until after midnight. (Magnitude −1.8 to −2.0.)

Saturn is a morning star in the southern part of Leo, rising shortly after midnight in the Northern Hemisphere and somewhat later in the south. The planet is moving more slowly as it approaches a stationary point, and its magnitude is still only +1.1. Saturn is thus a little brighter than Regulus, and should be easily recognized in this part of the sky.

December

Full Moon: 14 December *New Moon:* 29 December

Solstice: 22 December

Mercury is in inferior conjunction on 5 December, and comes to greatest western elongation (22 degrees) on 24 December. It should be possible to catch a glimpse of this elusive planet in the south-east before sunrise from any station having a clear horizon. Mercury is brightest after western elongation.

Venus is again at greatest brilliancy on 14 December (magnitude −4.4). Conditions on this occasion are in favour of northern observers, and by the end of the year Venus may be seen in a dark sky, since it then rises nearly four hours before the Sun. In southern latitudes the planet rises about two hours before sunrise.

Mars is now only a few degrees from the Sun and is not likely to be seen. The planet is moving rapidly towards conjunction with the Sun in January next.

Jupiter is now moving retrograde in Cancer, and at the beginning of the month is to the east of the star Delta Cancri. The planet passes to the north of this star in mid-December. Jupiter rises in the early evening (but about three hours later in southern latitudes) and is growing brighter as it approaches opposition in January 1979. (Magnitude −2.0 to −2.1.)

Saturn remains in the southern part of Leo, and is at a stationary point on 25 December. (See diagram in January notes.) For northern observers the planet rises in the late

evening, but in the Southern Hemisphere it rises at midnight in mid-December, and at the end of the year will be in the north at sunrise. The rings are now tilted at only 4 degrees, and Saturn remains at magnitude +1.0. The next opposition of Saturn is in March 1979.

Eclipses in 1978

In 1978 there will be two eclipses of the Sun and two of the Moon.

(1) *A total eclipse of the Moon* on 24 March, visible generally in Australia and New Zealand, and in Asia. The final stages will be visible in South Africa and eastern Europe. The eclipse begins at 14h 33m G.M.T. and becomes total at 15h 37m. Totality ends at 17h 08m, and the shadow of the Earth finally passes off the Moon's surface at 18h 12m G.M.T.

(2) *A partial eclipse of the Sun* on 7 April, visible only in the Antarctic and the extreme south of South America, and also in South Africa. At the Cape, the eclipse begins at 15h 15m G.M.T. and by 16h 09m about 40 per cent of the Sun's disk will be covered by the Moon; the Sun sets before the end of the eclipse.

(3) *A total eclipse of the Moon* on 16 September, the early stages visible in Australia and New Zealand, the final stages in Africa and the British Isles. The eclipse begins at 17h 20m G.M.T. and totality begins at 18h 24m. The total eclipse lasts until 19h 44m, and the eclipse ends at 20h 48m G.M.T.

(4) *A partial eclipse of the Sun* on 2 October, visible in the Arctic and the northern and eastern parts of Europe and Asia.

Occultations in 1978

In the course of its journey round the sky each month, the Moon passes in front of all the stars in its path and the timing of these occultations is useful in fixing the position and motion of the Moon. The Moon's orbit is tilted at more than 5 degrees to the ecliptic, but it is not fixed in space. It twists steadily westwards at a rate of about 20 degrees a year, a complete revolution taking 18.6 years, during which time all the stars that lie within about 6.5 degrees of the ecliptic will be occulted. The occultations of any one star continue month after month until the Moon's path has twisted away from the star. It will be realized that an occultation, like an eclipse of the Sun, is visible only in a restricted part of the Earth's surface, and only a few of these occultations will be visible at any one place in hours of darkness.

Only four first-magnitude stars are near enough to the ecliptic to be occulted by the Moon; these are Regulus, Aldebaran, Spica, and Antares. After a lapse of more than fifteen years, the star Aldebaran will again be occulted each month during 1978. This star is more than 5 degrees south of the ecliptic, and it will undergo a long series of occultations lasting more than three years. The series begins in Arctic regions, coming slowly south and then moving north again, but these events are not likely to be seen in western Europe or North America until the end of the year.

The planets, which have a motion of their own, are not usually occulted each month in this way. In 1978, there are two occultations of Venus and one of Mars, but the general conditions for viewing these are unfavourable.

Comets in 1978

The appearance of a bright comet is a rare event which can never be predicted in advance, because this class of object travels round the Sun in an enormous orbit with a period which may well be many thousands of years. There are therefore no records of the previous appearances of these bodies, and we are unable to follow their wanderings through space.

Comets of short period, on the other hand, return at regular intervals, and attract a good deal of attention from astronomers. Unfortunately they are all faint objects, and are recovered and followed by photographic methods using large telescopes. Most of these short-period comets travel in orbits of small inclination which reach out to the orbit of Jupiter, and it is this planet which is mainly responsible for the severe perturbations which many of these comets undergo. Unlike the planets, comets may be seen in any part of the sky, but since their distances from the Earth are similar to those of the planets their apparent movements in the sky are also somewhat similar, and some of them may be followed for long periods of time.

The number of comets under observation in any one year is much greater than is generally supposed. The following table compares the numbers of newly discovered comets, successfully predicted returns of periodic comets and comets being followed from previous years:

	1973	1974	1975	1976
New discoveries	9	5	13	5
Predicted and recovered	6	4	4	6
Still under observation	13	14	9	16
	28	23	26	27

In 1978, the following periodic comets are expected to return to perihelion:

Comet Tempel (1) was discovered in 1867, observed again at the next two returns and then lost until it was recovered in 1967, and seen again in 1972. This is a faint comet with a period of 5.5 years, and is predicted to return to the Sun in January.

Comet Arend-Rigaux, discovered in 1950 by two Belgian astronomers, has made four appearances and is expected again in February. It has a period of 6.8 years, and at perihelion can come inside the orbit of Mars.

Comet Tempel (2) has made fifteen returns, the first being in 1873. One of the more regular comets, its orbit is now well established, and the next perihelion passage will occur in February. Period 5.3 years.

Comet Wolf-Harrington, discovered by Wolf in 1925, was not seen again until it was recovered by Harrington in 1951. It was then observed at its returns in 1957, 1965 and 1971, and is expected again in March. This comet has a period of 6.5 years, and the orbit is inclined at an angle of 18 degrees.

Comet Whipple has been seen at each of its returns to the Sun since its discovery in 1933. The orbit lies wholly outside the orbit of Mars and has a period of 7.4 years. It is expected at perihelion in March.

Comet Tsuchinshan (1) is one of two comets discovered in 1965 at the Purple Mountain Observatory near Nanking. It has a period of 6.7 years and is predicted to return in May.

Comet Kojima was mentioned in the 1976 *Yearbook,* but subsequent calculations have shown that the comet made a close approach to Jupiter in 1973, and as a result the orbit has been altered considerably. The latest figures suggest that the period has increased from 6.2 to 7.9 years, while the eccentric-

ity of the orbit has also increased. Perihelion is now expected in May.

Comet Ashbrook-Jackson was first seen in 1948, and has made four appearances. It has a period of 7.4 years and, like Comet Whipple, it has an orbit of small eccentricity with its perihelion beyond the orbit of Mars. The next return is in August.

Comet Comas Solá, first seen in 1926, has been recovered at each of its returns, the last in 1969. This comet has a somewhat larger orbit with a period of 8.9 years, and at aphelion it is well beyond the orbit of Jupiter. Its next return to the Sun is expected in September.

Comet Schwassmann-Wachmann (1) has a nearly circular orbit with a period of sixteen years, which lies entirely between the orbits of Jupiter and Saturn. The motion of this comet is very much like that of a planet, and it is visible each year. It is remarkable for its sudden outbursts of brightness, which seem to have some connection with solar activity. Normally of magnitude 18, the comet has been known to reach magnitude 10.7. This occurred in 1959 and again in 1976. Smaller outbursts occur and this phenomenon is also known with other comets.

Meteors in 1978

Meteors ('shooting stars') may be seen on any clear moonless night, but on certain nights of the year their number increases noticeably. This occurs when the Earth chances to intersect a concentration of meteoric dust moving in an orbit around the Sun. If the dust is well spread out in space, the resulting shower of meteors may last for several days. The word 'shower' must not be misinterpreted—only on very rare occasions have the meteors been so numerous as to resemble snowflakes falling.

If the meteor tracks are marked on a star map and traced backwards, a number of them will be found to intersect in a point (or a small area of the sky) which marks the radiant of the shower. This gives the direction from which the meteors have come.

The following table gives some of the more easily observed showers with their radiants; interference by moonlight is shown by the letter M.

Limiting dates	*Shower*	*Maximum*	*R.A. Dec.*	
Jan. 1-6	Quadrantids	Jan. 4	$15^h 28^m + 50°$	
Mar. 14-18	Corona Australids	Mar. 16	$16^h 20^m - 48°$	
April 20-22	Lyrids	April 21	$18^h 08^m + 32°$	M
May 1-8	Aquarids	May 5	$22^h 24^m + 00°$	
June 17-26	Ophiuchids	June 20	$17^h 20^m - 20°$	M
July 15-Aug. 15	Delta Aquarids	July 25	$22^h 36^m - 17°$	
July 15-Aug. 20	Pisces Australids	July 31	$22^h 40^m - 30°$	
July 15-Aug. 25	Capricornids	Aug. 2	$20^h 36^m - 10°$	
July 27-Aug. 17	Perseids	Aug. 12	$3^h 04^m + 58°$	M
Oct. 15-25	Orionids	Oct. 20	$6^h 24^m + 15°$	M
Oct. 26-Nov. 16	Taurids	Nov. 8	$3^h 44^m + 14$	
Nov. 15-19	Leonids	Nov. 17	$10^h 08^m + 22°$	M
Dec. 9-14	Geminids	Dec. 14	$7^h 28^m + 32°$	M
Dec. 17-24	Ursids	Dec. 22	$14^h 28^m + 76°$	

M=moonlight interferes

Minor Planets in 1978

Although many thousands of minor planets (asteroids) are known to exist, only about 2,000 of these have well-determined orbits and are listed in the catalogues. Most of these orbits lie entirely between those of Mars and Jupiter. All of these bodies are quite small, and even the largest can only be a few hundred miles in diameter. Thus, they are necessarily faint objects, and although a number of them are within the reach of a small telescope few of them ever reach any considerable brightness. Of these, the most important are the 'big four', Ceres, Pallas, Juno, and Vesta. Vesta can occasionally be seen with the naked eye, and this is most likely to occur at a June opposition, when Vesta is at perihelion. This will occur again in 1978, when Vesta comes to opposition on 6 June, and is at perihelion at about the same time. The planet should be visible to the naked eye throughout the months of May, June and July, and in early June it reaches magnitude +5.5. Vesta is then in Ophiuchus, and has a rapid retrograde motion (see diagram in the May notes).

Ceres, the largest of the minor planets, comes to opposition in Sagittarius on 9 July, but does not exceed magnitude +7.1. Pallas is at opposition on 4 June, and this planet, whose orbit has the large inclination of 35 degrees, will then be well north of the ecliptic, and will be in Hercules, at a magnitude of +8.8. Juno, at opposition on 24 July, will then be in Aquila, its magnitude being only +9.2.

The latest observations have fully confirmed the small orbit found for the minor planet provisionally called 1976 AA (see 1977 *Yearbook*). In October 1976 an even smaller orbit was found for the minor planet 1976 UA, detected as a fast-moving object on plates taken at Mount Palomar. This planet has a

period of 0.775 year, and its mean distance from the Sun is only 0.84 astronomical unit (about 78 million miles). Calculations show that it must have passed the Earth at a distance of less than a million miles on 20 October. Only one other planet has ever come closer to the Earth; this was the planet Hermes, seen for a few days in 1937.

Some Events in 1979

ECLIPSES

In 1979 there will be four eclipses, two of the Sun and two of the Moon.

26 February—a total eclipse of the Sun, visible in N. America and as a partial eclipse in western Europe.

13 March—a partial eclipse of the Moon, visible in Australasia, Africa, Europe and America.

22 August—an annular eclipse of the Sun, visible in Antarctica.

6 September—a total eclipse of the Moon, visible in America, Australasia and Asia.

THE PLANETS

Mercury may best be seen in northern latitudes as an evening star about the time of greatest eastern elongation on 8 March, and as a morning star at western elongation on 19 August. In the Southern Hemisphere the best dates are 29 October (evening star) and 21 April (morning star).

Venus will be a morning star for the first half of the year, and will be at greatest elongation on 18 January. Superior conjunction occurs on 25 August.

Mars is in conjunction on 20 January, and there is no opposition during the year.

Jupiter is at opposition on 24 January in Cancer. After conjunction on 13 August it will be a morning star.

Saturn is at opposition on 1 March in Leo. Conjunction on 10 September.

Uranus is at opposition on 10 May in Libra.

Neptune is at opposition on 10 June in Ophiuchus.

Pluto is at opposition on 8 April in Virgo.

PART TWO

Article Section

Observatory Fitments

F. R. SPRY

A keen observer working in his observatory may, in my opinion, be described as one of the 'sighted blind'. He has one eye to the eyepiece and is viewing in the dark, not daring to put on a light which would destroy his night vision for an annoyingly long time. All he can see is his Moon, planet or star.

Under these circumstances, I suggest that so far as possible all accessories should be ready to hand and easily recognised by 'feel' alone. In my own case, I have what is termed a Crayford eyepiece mounting, in which each optic is in its own separate tube. Among the eyepieces, I can distinguish my 40 mm by its size and the 20 mm by its plain cylindrical shape, while the 12 mm is small and the tube has a collar at the end; the 6 mm is the same size, but has no tube collar. So each eyepiece tells me its size by its 'feel', and I do not have the frustration of having to use my eyes to identify them. But one must know where they are, and this means fitting out your observatory according to a pattern which you know by heart.

I have tried to put together some of the helpful devices that I and my friends have worked out, in the hope that they may benefit others.

One of the most useful, in my opinion, was devised by Roger Prout. If he wanted to make a study of—for instance—Ursa Major, the Great Bear or Plough, he would dictate on to a tape-recorder all the information given in a chosen book. He would take the tape in to the observatory, and follow the instructions: 'The first star in the handle is Alkaid'... with details of magnitude, spectrum and anything else relevant. Alkaid happens to be an ordinary star, but the method is particularly

valuable with regard to objects such as doubles and variables; one can also give taped instructions as to how to locate them. Moreover, a tape can be stopped and re-started at will.

No responsible viewer observes without recording what he has seen and done. For this, a clipboard is a 'must'. A thin piece of plywood or perspex with a spring clip at the top to hold the paper in place is the basic idea. It can be improved by the addition of a light from a small battery—preferably a red light, which can be controlled by a dimmer resistance from an old radio. It is surprising how little light is needed once your eyes are used to the dark after, say, half an hour's viewing, and almost all observers I know use a red light. Mine is housed in a 2 oz tobacco tin fixed to the underside of the board. You also need a clip for a pencil, tethered with string. Pen torches are to be recommended also, since they give only a small amount of light where it is most needed—and remember to lay in a stock of spare batteries.

How many eyepieces do you have, and how often do you change them when observing? Where are they when not in actual use—and how often have you dropped one? Observatory floors are often concrete, but a carpet on the floor can lessen the risks of damage; and eyepieces should be kept in a box, since if left on a shelf they can—and do—roll.

My 8.5 in. reflector is mounted so that when it is pointing to the zenith I can reach the eyepiece comfortably, and do not need any packing to give extra height; but when I have younger and smaller friends with me, extra height is often needed. Often it is surprisingly small—an inch or so. I keep a few pieces of 1-in. board, fairly wide (say 9 in. at least) for standing on during observing. Stools with legs are not to be recommended, because it is easy to forget where the legs are. If you slip, it is sheer instinct to grab at the telescope, which is not a very firm object—and the results can be most unfortunate!

I realize that some observatories are bound to be cluttered up with equipment, so that there is no room to spare. All I am trying to do is to suggest a few possibilities which may suit you.

If you are interested in occultations, it is useful to have a telephone handy for a time-signal. This is recorded on tape,

and a commentary can be added, together with a further time-check. This is far better than relying on memory alone. Using this method, Roger Prout and I once made an interesting discovery of a star's fading out during occultation, and what we said was recorded for reference later. (The star proved to be a very close binary.)

Some radio sets with short-wave band enable time signals to be available at any moment, from certain stations.

An old alarm clock is useful to remind you of the time to watch for something unusual, such as an occultation, and another clock can be set to sidereal time. Supplies of masked blanks for planetary sketches are useful—kept in a tin or box to protect them from the damp.

A driven telescope involves moving parts, so do not forget to keep the movable parts oiled. Then, some records call for the exact position of the observatory, and this can be worked on from a large-scale ordnance map; mine is 50 degrees 44 minutes 16.61 seconds north, 00 degrees 47 minutes 12.18 seconds west.

Elementary? Of course. But it is surprising how often the most elementary precautions and helpful devices are forgotten. Perhaps you have never considered one or two of the hints I have given here!

The Earth and the Moon

R. MADDISON

Although legend has it that Newton first began to think seriously about gravity when he saw or, according to some versions, felt an apple fall from a tree, it is much more likely that his interest was aroused by looking at the motion of the Moon, since it is obviously held in orbit around the Earth by some invisible influence. His attempts to explain its motion gave us the Law of Universal Gravitation which was later to play a major part in the discoveries of both Neptune and Pluto.

It was not until the latter part of the last century that measurements of the behaviour of very large masses over very large distances were of sufficient accuracy to show up minor deviations from Newton's Law, but such measurements led to the development of the theory of relativity rather than the downfall of Newtonian theory—the new ideas being a refinement of Newton's Law that made it applicable to a much wider range of properties and circumstances.

In spite of our present detailed knowledge of gravity and the way it works, the motion of the Moon is subject to so many outside influences that it seems almost too complicated to understand. The study of the Earth–Moon system is a two-body problem that is in itself relatively simple to solve. The three-body problem takes account of the added influence of the Sun and, although it is much more complex, it can be solved. The four-body problem involves the perturbations caused by Jupiter and is practically insoluble, but the ten-body problem, which would be a much more realistic representation of the Solar System, is far too difficult even to contemplate.

Over the last decade, the Apollo astronauts left several sets

of laser reflectors on the lunar surface, and it became possible to detect deviations in the motion of the Moon less than 10 cm in amplitude. As a result we now have access to measurements of the Moon's motion which reveal changes that seem almost impossible to describe, let alone unravel.

Most students of the Moon, however, are not concerned with the fine details of these perturbations although they are well aware of the more obvious phenomena such as the librations, the captured rotation, the tides, eclipses, and so on. The explanations of these phenomena are much more straightforward, and we will look at them in more detail as we review the overall properties of the system.

GENERAL PROPERTIES

The Earth

The general properties of the Earth–Moon system are summarized in Figure 1, but the following explanations may be useful.

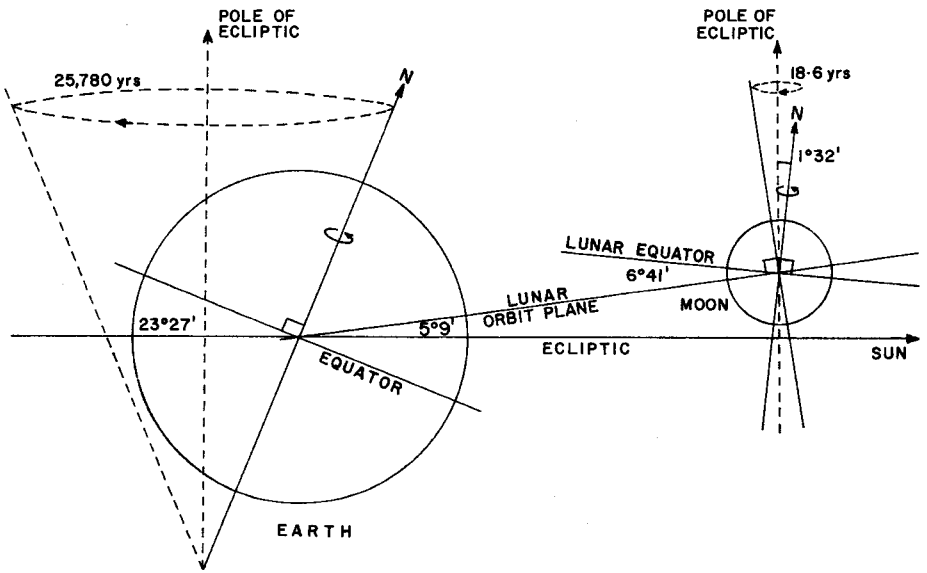


Figure 1.

The Earth has a polar diameter of 12,713 km, but because of its rapid axial rotation, and the consequent centripetal force, it bulges into an oblate spheroid having an equatorial diameter of 12,756 km. Detailed surveying using analyses of the motions of artificial satellites has shown that there are small deviations from this shape that are due to the distribution of continents and oceans so that, strictly for accuracy, the only way to describe the shape of the earth is to call it a geoid. Even this shape is not constant, because of the regular cyclical effects of the tides caused by the Sun and the Moon.

The axis of rotation of the Earth is tilted so that the plane of the Equator is at 23 degrees 27 minutes to the plane of the ecliptic (i.e. the Earth's orbital plane around the Sun). The direction of this axis in space, relative to the stars, is nearly constant, so that as the Earth moves around the Sun during a year the Poles are presented to it at varying angles and we have the effects of changing seasons. During summer, for example, the North Pole is tilted towards the Sun, whereas six months later it is tilted away from it. Careful observations over a long period of time will show that this axial direction is not exactly constant, but is slowly changing. At present, the Pole Star is about 1 degree from the true pole of the Earth's rotation, but during the next 12,000 years the true pole will move in an arc towards the star Vega. This effect, called precession, is caused by the gravitational force of the Sun acting on the tilted bulges of the Earth; the full cycle of complete rotation covers a period of 25,780 years.

The mass of the Earth is estimated to be 5.977×10^{24} kg, and if this figure is compared with the volume of the Earth we find an average density of 5.52 gm/cc. Geologists estimate that the average density of the surface rocks on Earth lies somewhere between 2.0 and 3.5 gm/cc and so it is clear that the deep underlying rocks must have much higher densities, and that there is probably a core of highly compressed material of density greater than 10 gm/cc.

The Moon

The Moon has a diameter of 3,476 km and has an almost

perfectly circular profile. Careful measurements have shown small deviations from circularity towards an elliptical cross-section. These amount to about 2 km, but the true shape is very difficult to assess because of the mountains and valleys that make up the lunar limb. It is clear that there is no pronounced equatorial bulge like the Earth's, but this would not be expected for such a slow axial rotation (27.32 days).

Analysis of the motions of several artificial moon satellites has, however, revealed irregular distributions of dense rocks immediately beneath some of the prominent maria: the mascons. This has shown that there is an earthward pointing bulge near the centre of the visible disk of about 3 km in height.

The orbit of the Moon around the Earth is approximately elliptical, and varies in distance between 363,263 km at perigee and 405,547 km at apogee. This varying perspective is apparent on Earth as a variation in the angular size of the Moon between 32′.9 and 29′.5, and this has important effects on solar eclipses.

The equatorial plane of the Moon is inclined to its orbital plane by 6 degrees 41 minutes, and this orbital plane is inclined to the ecliptic by 5 degrees 9 minutes. These inclinations lead to a precessional effect similar to the Earth's, but in this case the rotation is much more rapid, having a period of only 18.6 years.

The mass of the Moon is measured to be 7.35×10^{22} kg, which is a fraction 1/81.3 of the Earth's mass. This implies an average density of 3.34 g/cc, which is surprisingly low, and indicates, when compared with the surface density, much less concentration into a core than for the Earth.

Orbits

The orbital motions of bodies in a system are related to the gravitational centre of the system. In the Earth–Moon system the barycentre lies within the Earth at a point some 1707 km beneath the surface. This means that as the Moon rotates around the barycentre once a month so also does the Earth in an orbit of radius 4,671 km. In addition, both bodies are strongly affected by the Sun and, for example, the Moon experiences extra gravitational force accelerating its motion

while it is moving towards the Sun. On the other side of its orbit it moves away from the Sun, and the extra force slows it down.

On the whole, the Moon follows the general laws of planetary motion around a centre, and so it moves faster in its orbit at perigee, when it is closest to the Earth, and slower at apogee, when it is furthest away.

The Librations

At any instant of time an observer on Earth can see rather less than 50 per cent of the surface of the Moon. This is simply because the limb that he sees from a single point is defined by tangential rays of light radiating towards his eye. The closer he is to the Moon, the smaller is the area of its surface that he can see.

If he watches the Moon for several weeks he notices that the limb is not always in the same place. Sometimes he sees features in one area that were beyond the limb a few days earlier, while at the same time features that were clearly visible on the opposite limb are lost to sight over the horizon. He notices that the Moon appears to sway and nod as it moves along its monthly track around the sky. Careful mapping over a number of years shows that he can accumulate observations of up to 59 per cent of the total lunar surface. The remaining 41 per cent is, of course, hidden from view on the far side of the Moon.

This phenomenon is known as the lunar libration, and there are three main causes. First, there is the libration in latitude, which accounts for the nodding motion. The plane of the Moon's equator is inclined at 6 degrees 41 minutes to the plane of its orbit, so that sometimes the Moon's north pole is tilted towards the Earth by this amount. At such times an observer on Earth sees slightly beyond the north pole, while the south pole is out of sight. Approximately half an orbit later, due to the nearly constant direction of the rotational axis relative to the stars, it is the southern pole that appears tilted earthwards and the north pole that is out of sight (see Figure 2).

The second effect is the libration in longitude. In this case, the apparent swaying of the Moon is due to a mismatch of the

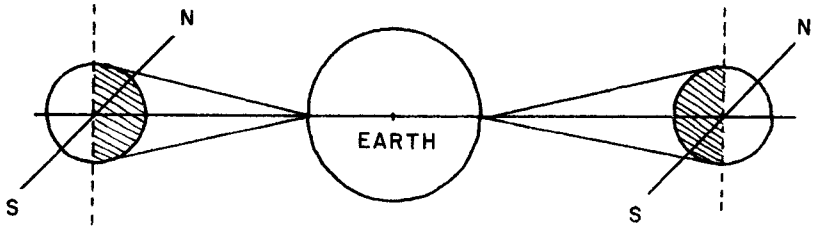


Figure 2.

constant rate of axial rotation and the varying orbital speed. Figure 3 is a plan view of the Moon's orbit; it shows the Earth at one focus and the successive positions of the Moon at quarter-month intervals. It should be remembered that the Moon's axial rotation is very constant, like a giant flywheel, and that it rotates through a quarter of a revolution in a quarter

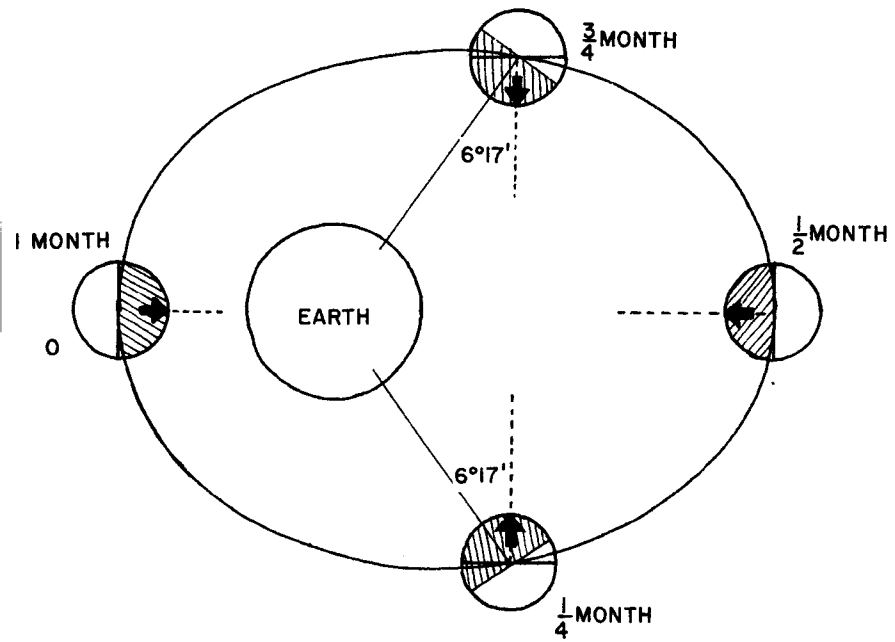


Figure 3.

of a month. The orbital speed, on the other hand, is described by Kepler's Second Law of planetary motion, so that the Moon covers more of its orbit near perigee than it does near apogee in the same time interval. The resulting apparent sway to east and west, of 6 degrees 17 minutes, allows an observer to see alternately beyond the mean eastern limb and then beyond the mean western limb.

The third cause is a purely local one involving the rotation of the Earth. In half a day an observer is carried around half of the Earth's circumference. He may be able to observe the Moon at sunset over in the east and then to follow it across the sky until it is in the west at dawn. During this time his view of the moon has changed because he sees it from different positions along a baseline of more than 12,000 km. This effect, small compared with the others, is called the diurnal effect.

The Tides

Since the Earth and the Moon are plastic bodies that can be deformed by large forces, for example by rapid axial rotation, then it is not surprising that one can observe the mutual effects of gravity on the shapes of the two bodies. This is the phenomenon of tidal deformation, and is observable in the solid masses of the Earth and Moon as well as in the oceans and atmosphere of the Earth. The situation is complicated by the presence of the Sun, with the result that the tide-raising forces

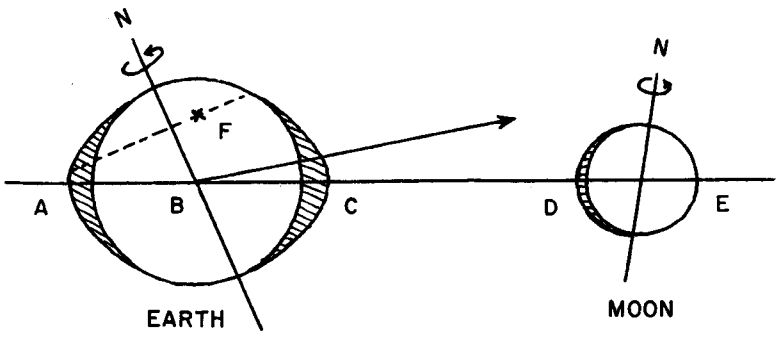


Figure 4.

are sometimes high, due to both bodies acting together and giving rise to 'spring' or very high tides. At other times the Sun and Moon act in opposition and give 'neap' or relatively low tides.

Most people are familiar with the fact that two tidal bulges occur on Earth, one on the moonward side and the other on the opposite side (points A and C in Figure 4) but many find it difficult to see why there should be a bulge on the side of the earth away from the tide-raising force. This is a difficulty that arises because we are used to feeling gravity acting downwards towards the centre of the Earth and we have an in-built frame of reference that regards the centre of the Earth as the origin in the system. The real situation becomes clear if we move our frame of reference to the point A on the far side of the Earth. We know that the force of gravity obeys an inverse square law, and we can see that the point A experiences a certain gravitational force due to the Moon. At the centre of the Earth, point B, we are much nearer to the Moon than at A and there is consequently a much stronger gravitational attraction. This causes a differential force between A and B that has the effect of pulling the centre of the Earth away from the edge at point A. As a result the seas are left behind and build up into a bulge. The same situation applies to the moonward side, so that there is a stronger attraction at point C than at the centre and this pulls the seas off the Earth into another bulge.

The existence of these two separate bulges causes two high tides each day at any point on the surface. Effectively the Earth rotates underneath the bulges. Figure 4 shows how a typical point (F) on the Earth's surface experiences these daily tides and how they are generally of different heights.

The actual tidal motion of the seas is quite small, but it is complicated and magnified by the presence of various surface features such as the continental masses. In some shelf areas like, for example, the Bay of Fundy in North America, the difference between high and low tide can be as much as 16 metres. In central ocean areas like the island of Tahiti, where there is much less disruption of free flow, the tidal range is as little as half a metre.

Tides also affect the solid body of the Earth, and the rocks distort to the extent of about a metre. The interesting fact is that this distortion relaxes as soon as the force is reduced so that it seems as if the planet behaves like a perfectly elastic sphere.

Tidal forces between two bodies are, of course, mutual and there is a matching distortion of the solid body of the Moon. It is estimated that the bulge in the centre of the visible face of the Moon is about 95 metres high but it is still not possible because of observational difficulties, to say that there is a bulge on the hidden side. Although these figures are so small the distortions have had several interesting cumulative effects on the Moon over the æons of time that have elapsed since the system was formed.

Captured Rotation

When the Earth–Moon system originated some four and a half thousand million years ago, it is fairly certain that the process involved was the gravitational capture of the Moon by the Earth, and that the bodies were never linked together as some of the early theories supposed. If this was the case, then it is most unlikely that the period of axial rotation of the Moon would be equal to its orbital period. The present situation is one that must have developed over a long period of time due to tidal interactions, and the chances are that the Moon's axial period was once much shorter than it is now.

The present captured rotation, where we always see the same face from Earth, is easy to explain if we remember that there is a tidal bulge near the middle of the Moon's visible face. The tide-raising force is primarily due to the Earth, and one would expect the bulge to be formed in the direction of this force. In the early days, however, the Moon would be rotating in a non-synchronous fashion, which would mean that the bulge would have to move over the lunar surface in order to stay in the same direction relative to the Earth. There would be a continuous plastic deformation of the Moon as it rotated underneath the bulge. This process would obviously involve considerable loss of energy because of the viscous drag of the bending rocks, and

it would become progressively harder to move the bulge as the Moon cooled down and became more rigid.

Over a long period of time this effect, which is like applying a steady braking force to a heavy flywheel, would slow the rotation down until the minimum amount of energy is lost in the process, and this would correspond to synchronous rotation where the bulge does not need to wander about over the surface. The same situation would have prevailed if the original period of axial rotation had been much longer than a month, but in this case the frictional drag would have slowly increased the rate of axial rotation.

In either case there would be a compensating effect on the Earth so that angular momentum is conserved, but there would be an overall loss of energy in the slight heating due to viscous drag.

The Recession of the Moon

Another interesting side effect of the tidal deformation of the earth is that its produces a gradual increase in the Moon's orbital speed which, in turn, makes the Moon slowly recede.

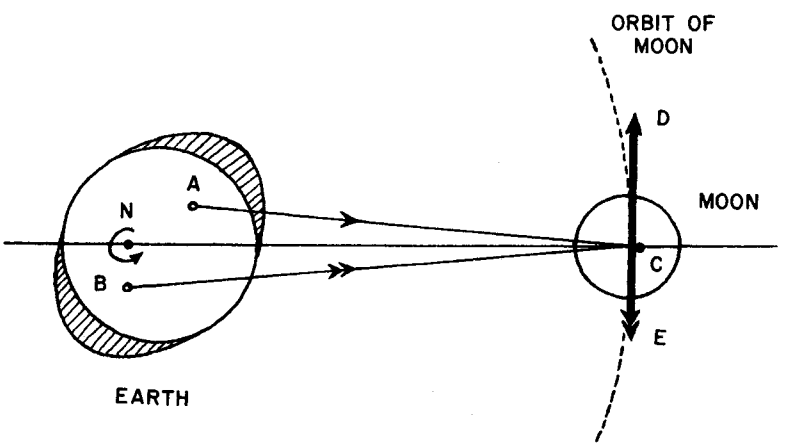


Figure 5.

Figure 5 is a plan view of the Moon's orbit. It represents an instantaneous view of what is, in reality, a state of dynamic equilibrium. The Earth–Moon gravitational interaction generates the two bulges in the viscous but plastic body of the Earth, but the Earth has an axial rotation which is very much faster than the orbital rotation of the Moon. The effect of the frictional drag is that the bulges are carried around by the Earth's rotation until a balance is set up between the drag and the tide-generating force.

On Earth, an observer has the impression that the tides occur before the Moon crosses his meridian, almost as if the tidal bulges are anticipating the presence of the Moon.

One way of representing this situation in terms of forces is to regard the Earth as a double object having two gravitational centres, for example, at the foci of the ellipse produced in a cross-sectional view. At equilibrium point A (Figure 5) is nearer to the Moon than point B and is therefore experiencing a stronger gravitational attraction than B. Both A and B are displaced from the central line so that the forces along AC and BC converge towards the centre of the Moon. These two forces may be resolved at the Moon into components that act in one case along the central line towards the Earth, and in the other case at right angles into the direction of the Moon's orbit. The components acting towards the centre add together, whereas the components in the direction of the orbit are in opposition. Because the force along AC is larger than that along BC, there remains a net unbalanced force acting on the Moon in the orbital direction which has the effect of accelerating its motion. It thus moves into an orbit of larger radius and modern estimates indicate a recessional speed of about 3.2 cm per year.

This effect is, of course, accompanied by a slowing of the Earth's axial rotation—since angular momentum has to be preserved—and there is indeed strong geological evidence that the days were shorter in the remote past than they are now, and there were more of them in a year.

The Roche Limit

The Moon's very slow recession can be used to suggest that

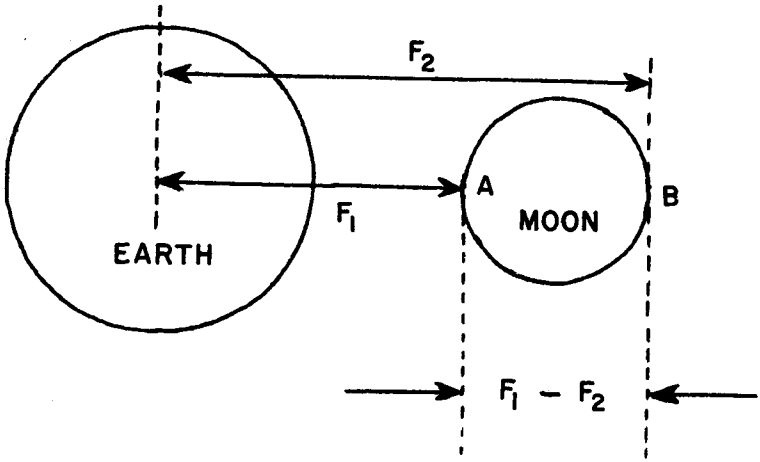


Figure 6.

perhaps, in the remote past, the Moon and the Earth were very close together and may in fact have been joined as a single object. There are, however, good dynamical reasons why such an object would be very stable, and it is difficult to see how it could break up even if it were only loosely held together and still contracting under gravity. There is also a good reason why something as large as the Moon would be unable to exist as a single object very close to the Earth, even if it had successfully been able to break away from it. The argument is as follows: the nearside of the Moon (at A in Figure 6) experiences a gravitational force F_1, due to the Earth. The far side experiences a much smaller force F_2, since it is 3,476 km further away. There is, therefore a differential force, $F_1—F_2$, acting across the Moon which is literally trying to pull it apart. Since both F_1 and F_2 are determined by an inverse square law of distance, it is possible to find a point at a critical distance from Earth at which this differential force becomes equal to the cohesive force that holds the Moon together. This cohesive force is the gravitational attraction that formed the Moon originally, and it is also the gravitational attraction any object would feel at its surface.

At a point closer to the Earth than this distance, the Moon would be torn apart by the differential force and the fragments would probably spread around the Earth and form a ring system exactly like the one around Saturn.

The particular critical distance for any planet is known as the Roche Limit, and it depends both on the relative dimensions of the bodies involved and their masses. In the case of the Earth–Moon system the Roche Limit is about 16,000 km, which is a point roughly 10,000 km above the surface of the Earth.

Eclipses and the Saros

One of the most helpful and fortuitous arrangements in astronomy is the near equality of the apparent angular sizes of the Moon and Sun as seen from Earth. On occasions the Moon's disk can exactly mask the brilliant solar photosphere so that we can see the corona, the chromosphere and prominences without specially designed equipment.

The varying distances of the Moon from Earth and the Earth from the Sun combine to give us a range of possible eclipses as the relative sizes of the Moon and Sun change. If an eclipse takes place when the Earth is at perihelion and the Moon at apogee, the Sun appears 1′ 35″ larger than the Moon and the Sun is not completely obscured. Under these circumstances the Moon's shadow does not reach the Earth (case B in Figure 7),

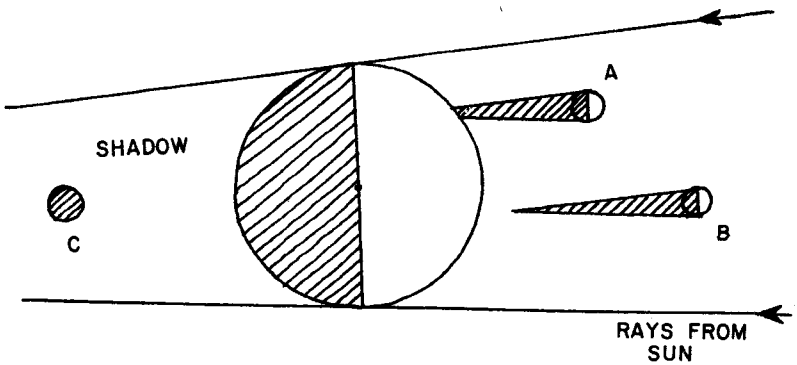


Figure 7.

and a bright ring of the Sun is visible around the Moon. This 'annular' appearance can last for a maximum of 12 min 24 sec. Conversely, when the Earth is at aphelion and the Moon at perigee (case A Figure 7.), an eclipse can occur where the Moon is 1′ 19″ larger than the sun and totality can last for as long as 7 min 40 sec. The great African solar eclipse of 1973 (June 30) was close to this situation, the greatest duration at that time was 7 min 5 sec.

In order to see a total eclipse one has to be at some point on the track of totality as the Moon's shadow moves across the Earth. Such tracks are at most about 250 km wide and it is therefore not surprising that many of the Earth's inhabitants have never seen one.

On the other hand, a total lunar eclipse, where the Moon passes into the much bigger shadow of the Earth (case C, Figure 7), is visible to anyone in the appropriate hemisphere of the Earth. The size of the Earth's shadow is such that a total eclipse of the Moon can last for up to 104 minutes. Because of this, there is a distinct impression that lunar eclipses must be more common than solar eclipses. In fact, the opposite is true. Figure 7 shows how the area of sky on the sunward side of Earth, in which a solar eclipse might take place, is considerably larger than the area covered by the Earth's shadow at night. This means that over a long period of time there are more solar eclipses than lunar eclipses.

Because the plane of the Moon's orbit and the plane of the ecliptic are not the same, eclipses do not occur every month. Figure 8 shows the orientation of these two planes just before a solar eclipse. One of the nodes, or points of intersection of the two planes, must be in the direction of the Sun, so that as the Moon approaches the node it must also pass in front of the Sun. If these conditions can be satisfied it can be shown that there may be between two and five solar eclipses in a year.

The prediction of eclipses is an art that was known to the ancient Babylonians, and it depended on a careful knowledge of the relative motions of the Sun and Moon and involved knowledge of the cycle of eclipses known as the Saros.

Solar eclipses, by definition, occur at new moon, so the time

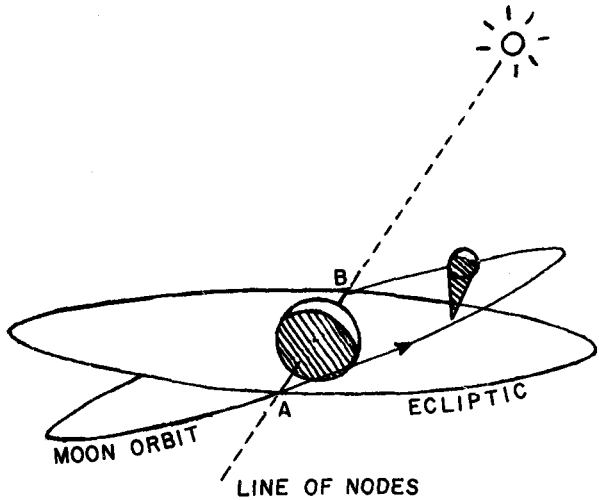


Figure 8.

interval between successive new moons, the synodic month, is clearly an important factor. It was noticed by the early observers that during an interval of 223 synodic months the Sun makes a complete circuit of the sky and reaches the same node at the same place on the ecliptic. This length of time is 6585.321 solar days, which is 18 yrs and 11⅓ days.

The shortest time required for the Sun to travel from and return to the same node is 346.6 solar days, and this interval is known as an eclipse year. It is less than a calendar year because of the effect of orbital precession, mentioned earlier, that causes a slow regression of the nodes around the ecliptic. Nineteen of these eclipse years contain 6585.4 days, which is almost precisely 223 synodic months. The coincidence of these two periods means that, if an eclipse occurs at a node at a certain point on the ecliptic, it will be repeated in almost the same point after 18 yrs 11⅓ days. This period of time is the Saros. In effect, a cycle of eclipses repeats with this periodicity and, although the tracks of totality will not coincide on the Earth's surface, the appearances of the eclipses will be the same.

If one takes account of the slight mismatch of 223 synodic months and nineteen eclipse years, and calculates the exact period of the complete cycle then the result is a series of eclipses lasting for about 1,200 years.

This brief summary of the more obvious properties of the Earth–Moon system shows how complex the interactions are. When we bear in mind that the Moon is our closest neighbour, and yet we do not fully understand its behaviour, we may realize how little we know of the rest of the Universe. This is probably why astronomy is such a fascinating pursuit!

The Zodiacal Light

J. C. D. MARSH

The constellations of the Zodiac are probably the most familiar (in name) after the Plough or Great Bear. There are twelve of them, each occupying about 30 degrees of the sky, although their shapes are by no means regular. They are threaded by that imaginary path called the ecliptic along which the Sun apparently moves throughout the year, passing through one constellation each month. Indeed, the Moon and the principal planets never stray more than a few degrees north or south of the ecliptic, so that the region of sky through which these objects pass is made up of a strip containing the Zodiacal constellations.

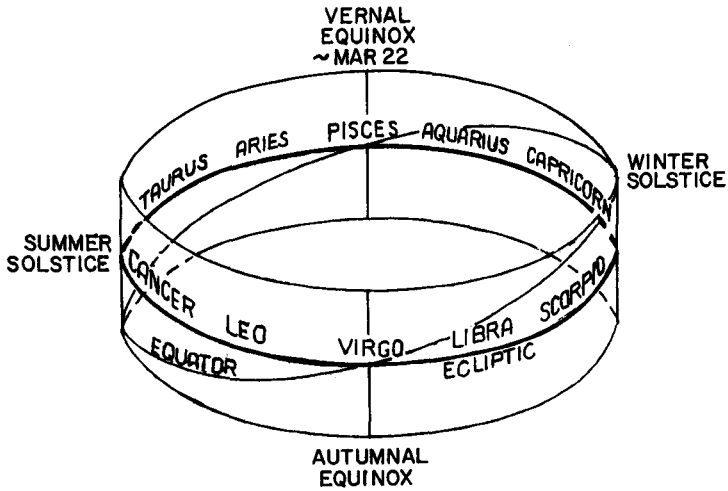


Figure 1. The Zodiacal constellations, ecliptic and equator

There is, however, another phenomenon of great delicacy apparently associated with the ecliptic which may be seen on a moonless night, when the atmosphere is at its clearest and most transparent. This is the Zodiacal Light.

About an hour after sunset, above where the Sun has dropped below the horizon, a faint diffuse area of light may be seen shaped rather like a slanting cone with its axis curving slightly back up along the ecliptic. At its base, it is perhaps 15-20 degrees wide and it extends upwards for rather more than 20 degrees. On long-exposure photographs, it can be seen to extend up to twice this distance.

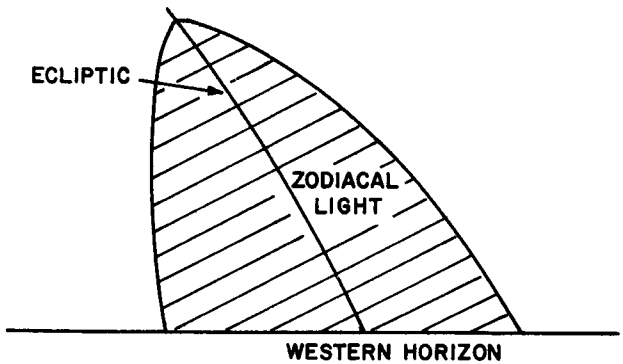


Figure 2. The Zodiacal Light after sunset

At its brightest, towards the centre of the cone, it is several times more luminous than the band of the Milky Way, and the distribution of light is more even than the familiar stippled effect of the Milky Way.

It is not too well seen from temperate latitudes, probably due to the angle which the ecliptic makes with the horizon and the long duration of twilight. In tropical regions, however, the axis of the cone is more nearly vertical and the twilight lasts only for a short time, so that from these zones the Zodiacal Light is more readily apparent. At greater angular elongations from the Sun, the Zodiacal Light may be seen to extend right across the sky from western horizon to eastern horizon to form a faint

but discernible zodiacal band, with a small bulge at the anti-solar point called the Gegenschein. However, from eclipse observations the Zodiacal Light can be seen to extend towards the limb of the Sun, where it merges with the solar corona.

It appears to have been first observed by Cassini, around 1683, who suggested even then that it was associated with reflected sunlight. However, it is such a delicate phenomenon that the definitive measurements necessary to ascertain its brightness, colour, spectrum and polarization were not possible until a comparatively few years ago. And it is these measurements which have now allowed this delicate and beautiful phenomenon to be fairly well understood.

The Colour and Spectrum

Roach and Jammick (1958) have correctly pointed out that the brightest portions of the Zodiacal Light are about 100 times too faint for colour perception to be possible with the normal human eye.

However, 12-colour photometry, i.e. measurements of the intensity of the light at precisely defined wavelengths and bandwidths, was undertaken over a long period in the grounds of the McDonald Observatory, Texas (elevation 6,800 ft) by Alan W. Peterson which yielded a colour index B-V = 0.61± 0.02 which compares almost exactly with that of the Sun, B-V = 0.62 (Allen, 1963). This gives a substantial reason for anticipating that what we see is reflected sunlight. Moreover, high-resolution spectroscopy of the Zodiacal Light carried out by Blackwell and Ingham (1961) revealed many individual absorption lines which are directly identifiable with the lines of solar spectrum. So it appears that sunlight plays a predominant part in generating the Zodiacal Light.

How does it do this?

The Composition of the Zodiacal Light

Polarization measurements suggest the presence of many small dust particles forming a zodiacal cloud. Exploratory calculations show that as well as larger particles the presence of particles with radii in the region in the range 0.1 to 0.2 microns

(a micron is one millionth of a metre) should not be excluded. Early theories suggested that particles with radii less than 0.1 to 0.8 microns would be blown out of the Solar System by the Sun's photon and corpuscular radiation, but there are several mechanisms which modify the effects of radiation pressure. Also there are several sources which give a continual supply of submicron particles. Another objection to submicron interplanetary particles is based on the argument that such particles are incompatible with the observed colour of the solar F Corona. However, there is no reason to assume that the size distribution of dust close to the Sun is the same as for the Zodiacal Light. In fact, large particles are continually being pulled into a smaller and smaller volume around the sun by Poynting-Robertson forces—submicron particles are not. Powell *et al.* (1967) proposed a belt model of interplanetary dust. In this, the interplanetary space in the plane of the ecliptic is arbitrarily separated into a system of belts such that the boundary of each belt coincides with the orbits of the planets. It is further assumed that all particle sizes and refractive indices are possible and that size distribution, number density and chemical composition of particles in one belt are completely independent of the same quantities in another. Finally, it is assumed that the particles are spherical.

Analysis of observations of the Zodiacal Light allow the size distribution of particles in each belt to be ascertained. These indicate that the radii of the particles lie in the range 0.08 to 1.5 microns, and the decrease in the number density with increasing particle size is very steep. Details are beyond the scope of this article, but the conclusions are clear; the dust particles near the Earth's orbit have radii between 0.08 and 0.2 microns and a dialectric constant lying between 1.4 and 1.8. There is little reason to expect the axis of the Zodiacal Light to coincide exactly with the ecliptic, for the ecliptic is defined by the orbital plane of the Earth, an insignificant planet. If the light is reflected by small solid particles, gravitational forces might be expected to be the dominant ones and a more significant plane would be the invariable plane of the Solar System which is inclined 1 degree 39 minutes to the plane of the ecliptic. Such a

small displacement is difficult to detect, even with delicate measurements, and for visual observations, quite impossible.

Thus, we may be fairly confident that the Zodiacal Light is due almost entirely to the scattering of sunlight by minute dust particles in the interplanetary space surrounding Earth, possibly concentrated by gravitational forces into a thicker belt coincident with the invariable plane of the Solar System.

As an observational phenomenon it is well worth looking for, preferably from a high site under clear dark conditions, whilst from a scientific point of view a study of the Zodiacal Light has yielded valuable information on the composition, density, size and distribution of dust particles in interplanetary space. Finally, a review article entitled 'The Zodiacal Light' by Blackwell, Dewhirst and Ingham in *Advances in Astronomy* and *Astrophysics 1967* offers a great deal of further information than this short article.

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Craters on Mercury and Mars

S. MIYAMOTO

Craters are characteristic landforms on the Moon, covering its whole surface. In 1965, Mariner 4 detected craters on Mars also, and more detailed studies of them have been carried out from Mariners 6 and 7 (1969), Mariner 9 (1971) and Vikings 1 and 2 (1976). And in 1974, Mariner 10 discovered that Mercury, also, is cratered, so that it may be that craters are characteristic of terrestrial-type planets. However, the craters in each of these worlds show their own individuality in their morphological features.

The observed hemisphere of Mercury shows craters which look very like those on the Moon, and ray-craters also exist. Many of the Mercurian craters have central peaks, some of which have well-developed outer slopes and cover large areas of the inner floor. In some cases the peaks exhibit summit vents.

On Mars, craters are less abundant than with Mercury or the Moon, and their distribution is more restricted. Some are of 'lunar' type, but there are others which may be termed volcanic domes, showing a large summit vent rather than a crater. There are also various other features on Mars, such as large grabens, valleys, and strato-volcanoes.

We are now able to arrange craters in definite classes. At the end of the sequence come craters such as Ptolemæus and Clavius, on the Moon—large, with polygonal walls and rather flat floors. The surrounding areas are covered with tectonic networks, and the crater walls are associated with these network features.

At the other end of the sequence come the strato-volcanoes,

Figure 1. Ptolemæus, Alphonsus, Arzachel

such as Olympus Mons, Arsia Mons, Pavonis Mons, and Ascræus Mons in the Tharsis region of Mars. Between these extreme forms comes Tharsis Tholus, east of Ascræus Mons. Its outer wall is too well developed for it to be regarded as a true crater, but its summit vent is much larger than for any terrestrial volcano. The diameter of the feature is 170 km, and there are other similar structures in the same area. Arsia Mons may be included in the same group. Morphologically, it may be classed as a giant depression, but the height of the crater wall above the floor is about 27 km, and the crater itself is 100 km in diameter. Its outer slope is not symmetrical, but is about three

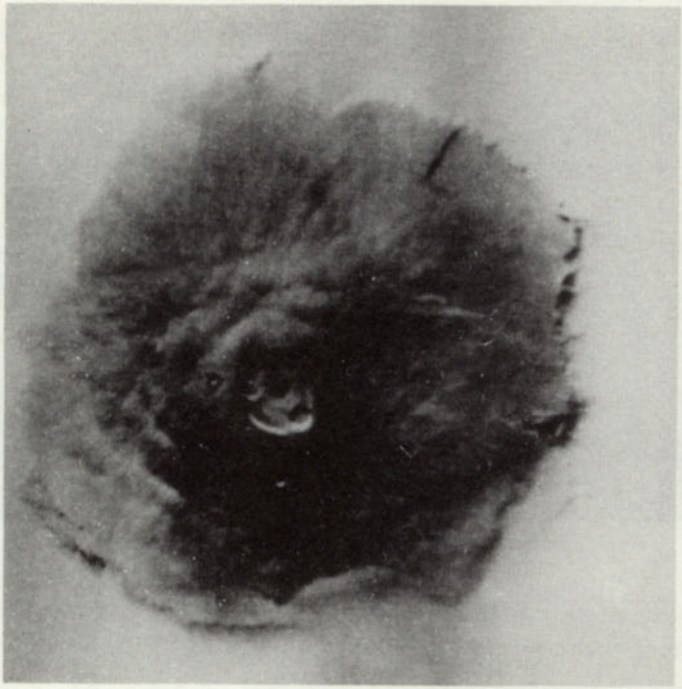

Figure 2. Olympus Mons

times greater than the diameter of the crater. Arsia Mons and Tharsis Tholus seem to be intermediate morphologically between calderas and scoria cones.

Interesting types of craters were revealed in the Chryse region of Mars by the Viking photographs. Arandas (15 degrees west, 43 degrees north) is 25 km in diameter, and is surrounded by a lava-flow; the central peak is very well developed, and covers much of the floor. Another crater in the Chryse region, Yuty—18 km in diameter—shows a lobate pattern of lava flow; the central peak is a gigantic cone, crowned with summit craters. Many other craters in Chryse are similar in form.

As is well known, craters with lobate lava flows are rare on the Moon, and on Mercury they are rare and inconspicuous.

Figure 3. Tharsis Tholus

Craters of this kind may be placed in our crater sequence between formations of lunar type and those of the Arsia Mons type.

Double-ring craters are common on Mercury; Renoir, Bach and Bernini are good examples. They have, in fact, central calderas instead of central peaks.

In the Cydonia region of Mars there is a 40-km crater which is unlike Arandas or Yuty in that the outer region, beyond the wall, is a flat plane pitted with craterlets; the floor of the crater is hummocky—a jumble of domes and hills with numerous cracks and rocky blocks, so that it may represent a kind of double-ring crater. The walls are incomplete, so that either they have been destroyed or else they were never formed. This marked morphological difference between the inside and the outside of the crater suggests that it was formed by a quiet process rather than by violent impact. Craters with lobate lava fields and those with rough floors may lie, in the crater sequence, between the 'lunar' type and the Tharsis Tholus dome.

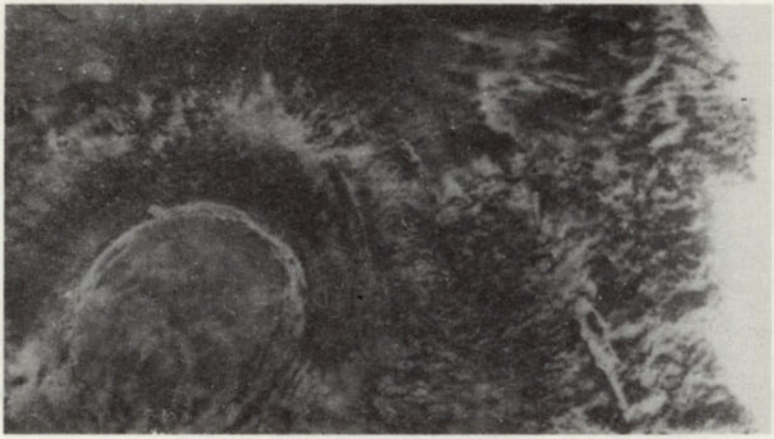

Figure 4. Arsia Mons

This morphological sequence of craters suggests a gradual change of volcanic activity, from the fissure eruption to the central eruption, which may be associated with the gradual evolution of the crust—thin and soft at first, hard and thick later. The thin primitive crust would be easily fractured into tectonic plates by mantle convection and other subcrustal processes. Then, by the escape of the volatile components of the magma through tectonic fissures, the underground pressure would be reduced, so that there would be subsidence of the block plates. According to the endogenic hypothesis, this happened during the formation of lunar craters.

As the crust thickened, the volcanic activity would change from fissure eruptions to the central gas and magma eruptions; the crater would become smaller, and become circular rather than polygonal. During the last stages of crustal development, the crust itself would be hard enough to support a magma reservoir, and cinder-cones and strato-volcanoes would be built up, as on Earth. In this respect the Martian crustal features are particularly interesting. The Noachis-Aeria highland deserts are covered with lunar-type craters, while craters are lacking in the Amazonis and Tharsis deserts; instead, we find strato-volcanoes and volcanic domes with large vents. In

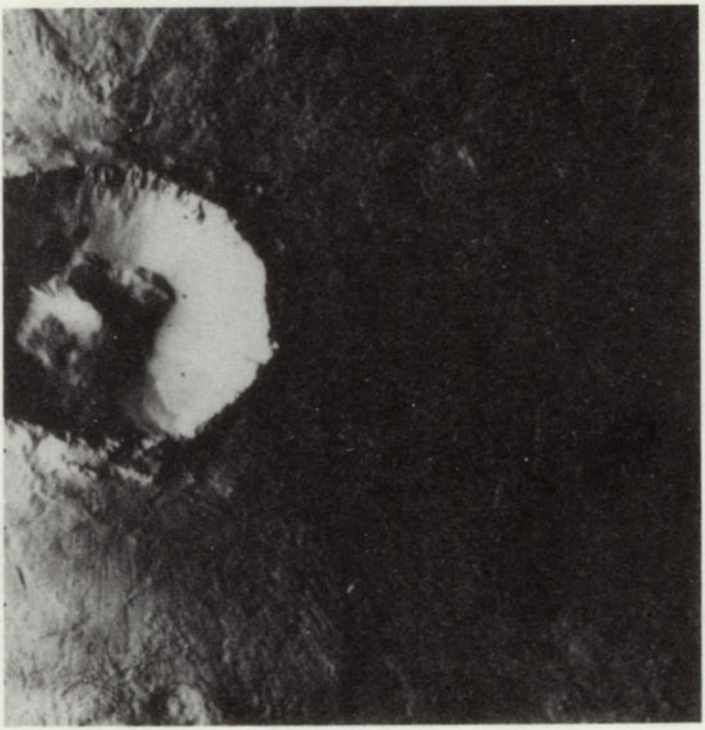

Figure 5. Arandas

general, the Martian crust may be in an intermediate stage of evolution—more advanced in Amazonis than in Noachis.

The similarity of Mercurian craters to those of the Moon suggests that the crust of the planet is in the same stage of evolution. On Mercury, many of the craters have well-developed central peaks or double ring structures, and some of them are surrounded with lava fields.

One characteristic of the lunar scene, though not on Mercury, is the so-called beak pattern. Most of the lunar craters, except those in the polar regions, have walls broken at their north and south points, and the outer walls there extend away from the craters, swelling up in a north-south direction. Typical beak patterns are associated with Alphonsus and

Figure 6. Yuty

Arzachel. This suggests global appression in an east-west direction at the time of crater formation. J. E. Spurr attributed it to the shrinking of the Moon by the escape of volatiles.

On Mercury the beak patterns are less conspicuous, though the numerous scarps suggest that appression took place there also in milder form. The mean density of Mercury is greater than that of the Moon, and comparable with that of the Earth, so that there is certainly a metallic core; the gaseous content may be less.

The origin of craters on terrestrial planets is still a matter for

Figure 7. Crater in Cydonia

debate. According to the impact theory, the basic cause is bombardment by meteoroids or asteroids, together with subsequent volcanic activity to account for the lava-flows and the heterogeneous chemical composition of the materials. We must also consider the craters on the two dwarf satellites of Mars, Phobos and Deimos, which were discovered by Mariner 9 and have been more closely studied by the Viking orbiters. It has been generally assumed that these craters are of impact origin, and certainly we cannot expect that small bodies of this kind would possess enough internal energy to produce craters. However, it is possible that craters could be formed, during the cooling stages of Phobos and Deimos, by the effects of a second 'boiling'. With a mixture of water vapour and liquid silicates, a decrease in temperature would result in the crystallization of the silicates, together with a relative increase in vapour which would be soluble only under very high pressure. Further cooling and crystallization would induce ebullition, and therefore craters could be formed by the cooling of small satellites of the Phobos and Deimos class.

Many craters on the Moon and Mercury, and craters and strato-volcanoes on Mars, are much larger than any corresponding formations on the Earth. Although Mars, the Moon, and Mercury are smaller than the Earth, so that presumably they have never had as much internal energy, the scale of landforms depends also upon the condition of the crust. If a lunar-type crater is basically the depression of a crustal plate by a decrease in underground gas pressure, its size would not be expected to be directly related to the amount of available energy. On Mars, gigantic volcanoes such as Olympus Mons could hardly be formed after the crust had thickened up. Finally, we must not forget that any high mountains and deep canyons on the Earth are affected by erosion and by crustal activity to a much greater extent than upon the other terrestrial-type worlds.

The Atmosphere of Mars; Past, Present and Future

GARRY E. HUNT

1. *Introduction*

The planet Mars has always interested astronomers, for it is the only member of our Solar System that superficially resembles the Earth. Early telescopes showed distinct markings that could be followed as they rotated with the planetary surface. The appearance of light orange and darkish grey-blue coloured areas that change on a seasonal basis and a disk crowned at the poles with brilliant white caps provided further information for early astronomers to speculate that the Earth and Mars were planetary twins.

The space missions to Mars launched during the last decade have drastically changed our knowledge of Mars. From the Mariner 4 mission, the planet appeared bleak and moonlike and the surface pressure on Mars was found to be less than 1 per cent of the Earth's. This value is lower by a factor of 10 than that previously estimated from Earth-based observations. Mariners 6 and 7 space missions extended these observations. Optically thin hazes were seen above the limb in several places, although these hazes did not noticeably obscure the surface features during the period of encounter the atmosphere was free of these clouds. The light and dark markings were attributed to some kind of atmospheric interaction with surface dust controlled by local topography. Even at this stage, Mars did not appear to be an atmospherically active planet.

When Mariner 9 reached the planet on 13 November 1971, and the Russian Mars 2 and 3 space probes on 2 December 1971, the greatest dust storm in more than a century was raging on the planet, almost totally obscuring the surface. When the

storm cleared it revealed a totally new look to Mars; a geologically, meteorologically, and just conceivably biologically active planet. Now a further dimension has been added to our understanding of Mars through the four Viking spacecraft, the two landers which safely touched down on Mars on 20 July 1976 and 3 September 1976 respectively, complemented by the two orbiters. In addition to the search for life, Viking has made important discoveries related to the fundamental geophysical problems of the cause of the Martian channels, the nature of the polar caps, the size of the ancient atmosphere, which collectively help to provide a more complete understanding of the past, present and possibly the future of the Martian atmosphere.

TABLE 1 Physical Data

	Venus	Earth	Mars
Mass (10^{26} g)	48.7	59.8	6.43
Mean radius (km)	6049	6371	3390
Mean density (g cm^{-3})	5.26	5.52	3.94
Inclination of equator to orbit	3°	23.5°	25.2°
Orbital eccentricity	0.007	0.017	0.093
Length of year (Earth days)	225	365	687
Period of rotation (days)	-243	1.0	1.03 (= 1 sol)
Satellites	0	1	2

2. *Atmospheric Structure and Planetary Topography*

The atmosphere of Mars is thin compared with that of the Earth. The average surface pressure is in the neighbourhood of 6 millibars (m bar) while a typical terrestrial value is 1,013 m bar. Surface pressures are primarily a function of altitude which on Mars may vary widely through the topogra-

TABLE 2 Planetary Data

	Venus	Earth	Mars
Distance from Sun (Gm)	108	150	228
Solar flux (wm^{-2})	2597	1370	595
Albedo	0.71	0.33	0.16
Cloud cover (%)	100	50	6
Effective temperature (K)	244	253	216
Surface temperature (K)	730	288	216
Scale height (km)	4.5	7	10
Main atmospheric gases	CO_2	N_2, O_2	CO_2

phic features of spots, volcanoes, calderas and rift valleys. Typically higher values are found in depressed areas or basins. A pressure of 8.9 m bar has been determined spectroscopically in the Hellas Basin, which is centred at 40 degrees south and 290 degrees west. The basin is approximately 1,800 km north-south and 2,200 km in an east-west direction with the eastern slope noticeably less steep than the west. It is also a region of meteorological importance since many of the global dust storms seem to start in this region. Some of the lowest measured pressures are 1 m bar at the summit of Pavonis Lacus (1 degree north, 113 degrees west) and about 1.5 m bar at the top of Arsia Mons (11 degrees south, 119 degrees west). The altitude of Arsia Mons is estimated to be 19 km and the average slope of the structure to be approximately 3 degrees. Mars posseses a very rough surface by terrestrial standards, with large variations in the surface topography to the extent that the surface relief of the planet is approximately equal to the atmospheric scale height. Numerical experiments of the general circulation of the Earth's atmosphere suggest that orography is fundamental for producing the more permanent atmospheric patterns. On Mars therefore, we anticipate the orography to play a major role in characterizing the atmospheric motions.

Temperatures in the thin lower atmosphere of Mars are

much lower than those on the Earth. The average surface temperature is approximately 210°K. The temperature ranges from 132°K in the polar regions to about 220°K near the equator. The daytime values reach to almost 250°K at the equator during the equinoxes. The coldest temperatures ever recorded anywhere on the Earth in the past few thousand years are higher than the average mid-latitude Martian temperature. The thin atmosphere will respond rapidly to the incident solar radiation, so that we may expect large diurnal temperature variations which has been confirmed by the measurement made by the Viking landers in Chryse and Utopia regions. There are currently the most distant meteorological stations in the Solar System. In the Chryse region, the Viking experimenters find a maximum temperature of 241.8°K occurs at +1500 local lander time (LLT) and the minimum of 187.2°K occurs at +0500 LLT, shortly before sunrise. These variations are much larger than we find on the Earth during the course of a day. For example, China Lake, which is part of a broad, dry basin in the Mojave Desert, California, the temperature variation is from 292°K to 311°K, although the times of temperature maximum and minimum are the same at both the Martian and terrestrial sites. The similarity in times of maximum temperature can be explained through the dominant heating mechanism near the surface being convective transfer from the ground. The maximum temperature is reached when the ground temperature has cooled enough so that convection effectively ceases. This occurs about 15.00 local time on both planets, since the atmospheric heat capacity and the rate of convection are both proportional to the air density. Consequently, the time of maximum air temperature is approximately independent of the air density.

The polar caps on Mars have been a source of fascination since the first telescopic observations of the planet. Scientifically, they play a very important role in the meteorology and climatology of the Martian atmosphere. The northern polar cap has a polygon shape and extends to about 60 degrees latitude at maximum. The measurements from the orbiting Viking spacecraft during the northern summer showed that the

residual cap has a temperature of about 205° K and an albedo of nearly 43 per cent. This temperature was high enough for any carbon dioxide to evaporate from the surface. Furthermore, the Viking measurement found that the water vapour concentrations were a maximum over the residual north pole. There now seems little doubt that the residual pole is composed of dirty water ice, which has important implications regarding the future climate of Mars. The south polar cap is perennial in nature, and at its maximum extends as far as 50 degrees south. This is further than the north polar cap as a consequence of the longer southern hemisphere winter, but the transient cap extension is quite thin. The Viking measurements of the south pole in winter were equally unexpected, since a minimum temperature of 132° K was observed. This is more than 10° K colder than expected, and therefore below the CO_2 condensation point at the surface pressure of the neighbourhood. The observation implies that the annual atmospheric condensation is less than previously assumed, and that either thick CO_2 clouds exist at the 20 km level or that the polar atmosphere is locally enriched in non-condensable gases.

Both polar regions show evidence of laminated terrain which extend to about 70 degrees latitude and resemble stacked plates. The uppermost layer being the permanent cap deposit. There is now strong evidence to suggest that these laminæ indicate climatic cycles on Mars with each layer formed during a particular epoch.

3. *Atmospheric Composition*

The thin Martian atmosphere, probably formed principally from the emission of gases by the giant volcanoes which lie along the Tharsis ridge, is mainly composed of carbon dioxide with traces of water vapour, carbon monoxide, oxygen, ozone, argon, nitrogen, krypton and xenon. The minor constituents, argon, nitrogen, krypton and xenon are extremely important discoveries which provide invaluable information on the ancient Martian atmosphere which we discuss in the following section. The abundances of H_2O, O_3 and O_2 are all extremely variable with both season and geographical location.

TABLE 3 Composition of the Martian Atmosphere

	Abundance (%)
Carbon dioxide	95
Carbon monoxide	0.16
Oxygen	0.1 to 0.4
Nitrogen	2 to 3
Argon	1 to 2
H_2O	Variable
Ozone	3×10^{-6}
Krypton	30×10^{-6}
Xenon	$< 1 \times 10^{-6}$

Upper limits of gases not detected in the Martian atmosphere

	Present upper limit	*Expected value*
Methane	120 ppm	25 ppm
Ne	10 ppm	5 ppm

Ozone has been detected in the Martian atmosphere during both the Mariners 6/7 and Mariner 9 missions, although the amount detected is only 3-57 μm atm which is less than 1 per cent of the amount in the Earth's atmosphere (0.3 con. atm). In the summer, the amount is less than 3 μm atm, increasing in autumn in association with the polar hood until a maximum amount is found in winter. In 1971/72 this corresponded to 57 μm atm over the polar hood and 16 μm atm over the polar cap. In the spring, the amount over the polar cap was found to decrease monotonically until at the beginning of the summer, the ozone has disappeared. Throughout the Mariner 9 mission, ozone was not observed in the equatorial region.

The ozone in the Earth's stratosphere acts as a shield to the harsh UV rays of the Sun, which would be harmful to all forms of life, both human and animal, which reside on the surface. But on Mars, the limited amount of ozone is a poor barrier, so that UV rays of light at wavelengths as short as 1,900 Å are known to reach the planetary surface. It is possible that these rays play a major role in photocatalytic reactions that convert the red iron oxide coating of the surface into a superoxidized

state. The superoxide surface, although a very powerful oxidizing agent, could destroy organic molecules. But this does not, in itself, preclude the presence of life which could always reside under the soil or in more sheltered places, rather than on the hostile surface of the planet.

The amount of water vapour in the Martian atmosphere (and also on the planetary surface) has always been a subject of speculation and debate, although recent Earth-based observations have confirmed its geographical and seasonal variation. The Viking observations have added further dimensions of the diurnal variation and high spatial resolution of these important measurements. They show very little water vapour in the Mars atmosphere in the southern hemisphere (0 to 3 pr μm) with a gradual increase across the equator to northern latitudes. A value of 30 $\lambda\mu$m was observed in the Elysium-Amazonis region early in the Viking mission.

It is generally agreed that the water vapour is confined to the lowest layers of the atmosphere, which undergoes a large variation of temperature during a Martian day (sol). The sublimation of a layer of exposed ice deposited on the surface must be discarded as the direct source of the vapour observed, since its lifetime in the solid phase at dawn would be too short to give the observed slow increase in vapour. The rapid evaporation of the surface frost at sunrise could, however, be the initial source of a ground fog, whose subsequent evaporation would produce the observed increase in vapour. The diurnal variation of vapour from exposed surface ice that does not pass through a second condensation phase to form an atmospheric haze layer would characteristically reach a maximum very early in the day. Ground fogs have been seen in canyon regions of Mars in many of the Viking photographs.

The largest abundances of water vapour have been found in the latitude band of 70 degrees to 80 degrees north in the northern midsummer season, with values of more than 80 pr μm. These values imply near surface atmospheric temperatures of about 204°K in the polar region which are incompatible with the survival of a CO_2 polar cap, which at Martian pressures would require a temperature of 150°K. The

summer residual ice cap (above 82 degrees north) and the fragmented patches of ice remaining in the band 70 degrees to 80 degrees north are therefore, water ice. The amount of water represented by the polar ice caps is still in doubt. However, the thickness of the polar ice can be estimated from the scale of surface roughness, which the thickness must exceed in order to produce features visible in the orbital photography as extended regions of high albedo. It is estimated to be between 1 m and 1 km thick, which if all released at once, is sufficient to cover the entire planet in 0.5 m of water!

But is this the only potential reservoir of water on the planet? Is it possible for running water to have cut the channels observed? To answer these fundamental questions we need to know more about the ancient Martian atmosphere and the meteorological processes on the planet.

4. *Trace Constituents and the Ancient Martian Atmosphere*

Noble gases and nitrogen discovered in the Martian atmosphere provide fundamental information that indicates a much greater carbon dioxide atmosphere in the past. Since noble gases are chemically inert and are not removed from the atmosphere through chemical reactions, they provide direct evidence of the volatile compounds released from a planet during its evolution. Chemically reactive substances, such as water, carbon dioxide and to a lesser extent nitrogen, are less reliable indicators since they can be trapped in the surface through the formation of nitrates and carbonates.

The Soviet space probe Mars 6 indicated that as much as 35 per cent of the atmosphere may be composed of argon. But this is a gross overestimate, when Viking measured about 2 per cent at the surface of the planet (Table 3). The Majority is Ar^{40}, produced from the radioactive decay of K^{40} in potassium-rich minerals. A tiny fraction is Ar^{36}, a non-radiogenic isotope which may be traced directly to the inventory of volatile compounds in the material that formed the planet.

Two other noble gases, krypton and xenon, have also been discovered on Mars, with krypton the more abundant of the

TABLE 4 Comparison of the isotope ratios in the Martian and Terrestrial Atmospheres

Species	Mars	Earth
N^{15}/N^{14}	0.0064 to 0.0050	0.00368
C^{13}/C^{12}	0.0118 ± 0.0012	0.0112
O^{18}/O^{16}	0.00189 ± 0.0002	0.00204
Ar^{36}/Ar^{38}	4 to 7	5.3
Ar^{36}/Ar^{40}	$(3.636 \pm 0.02) \times 10^{-4}$	4×10^{-3}
Xe^{129}/Xe^{132}	2.5 (+2 or −1)	0.97

pair. But what do these measurements, in addition to the important detection of nitrogen, tell us about the ancient atmosphere on Mars? It would seem very unlikely that Mars had a massive original atmosphere, produced, for example by accretional heating, which was subsequently reduced to its present state by extensive solar wind sweeping. If this were the case, we would expect the Ar^{36}/Kr to be much lower than the value found in the Earth's atmosphere or in the primordial gas in meteorites, since the argon would be swept off more efficiently than krypton in the upper atmosphere where diffusion separation occurs. Since the Ar^{36}/Ar^{40} ratio is less on Mars than it is on the Earth by a factor of 10, this may suggest that Martian degassing is less complete than on its terrestrial counterpart. Furthermore, through a scaling of the Ar^{36}/CO_2 ratio of the Earth for Martian conditions, suggests that the ancient atmosphere may have been thicker with a surface pressure of about 100 m bar.

But the nitrogen measurements provide stronger evidence of an even more abundant ancient atmosphere. The Viking measurements show an enrichment of nitrogen 15 over nitrogen 14 that appears to be due to a differentiation of the lighter isotope caused by a photochemical processes. At a maximum, the nitrogen measurement indicates that the carbon dioxide atmosphere could have reached a pressure as great as the Earth's (1 m bar). Then if all the volatiles had been released at once, the water could have covered the planet to a depth of

200 m, so that the deep dusty basins would then have been oceans.

Thus Mars may be viewed as having degassed and produced a thick atmosphere early in its history. The arrival of this early atmosphere in turn may indicate that most of the volcanic activity on Mars took place three to four æons ago. Certainly, in these early stages of the planet's history, water would have run freely on the surface of Mars.

5. *Martian Meteorology*

The weather systems of the terrestrial planets, Earth, Venus and Mars are driven by the Sun, where the fundamental external drive for their planetary scale circulations is the difference of insolation between equator and poles. However, the resultant temperature contrast between equator and pole varies greatly between the planets. In terms of mean atmospheric temperature, the contrasts now are less than 2 per cent for Venus, 16 per cent for the Earth and 40 per cent for Mars, while for an atmosphere in radiative equilibrium, the contrast should be close to 100 per cent depending upon the inclination of the rotational axis.

TABLE 5 Meteorological Data

	Venus	Earth	Mars
Response time of the Whole Atmosphere (secs)			
Radiation	10^9	10^7	2×10^5
Dynamics	3×10^4	3×10^3	5×10^3
Surface conditions	chemical equilibrium	liquid/ solid	dusty
Cloud amount (%)	100	50	6
Adiabatic lapse rate (k/cm)	1.01×10^{-4}	9.7×10^{-5}	4.5×10^{-5}
Topography as fraction of atmospheric scaleheight	0.2	0.3	1.0

The most important single factor which controls the planetary climatology is probably the total mass of the atmosphere, which is proportional to the ground pressure. The radiative relaxation time is proportional to the atmospheric mass and only when it is short compared to the relaxation time for dynamical processes can the atmosphere be in radiative equilibrium, with large temperature contrasts between equator and poles. Otherwise, the planetary scale motions will play the dominant role in heat transfer and will tend to give rise to an atmosphere with little horizontal temperature contrast and an adiabatic lapse rate in the vertical. It is apparent from the relationship between the radiative and dynamical relaxation times given in Table 5 that the thin Martian atmosphere is closest to radiative equilibrium, while the massive lower atmosphere of Venus is under strong dynamical control.

We have seen earlier that the lower Martian atmosphere undergoes large diurnal changes in temperature, and these changes give rise to strong diurnal wind systems. Some direct information has been obtained from the meteorological measurements made by the Viking landers on the surface of the planet. During the first 20 sols the mean wind velocity was from the south at 2.4 ms^{-1}. These lower level winds are strongly controlled by the local topography, and the wind direction varies throughout the day. During this initial period the winds remained light, and daily reproducible, with velocities less than 8 ms^{-1}, far below those of at least 30 ms^{-1} necessary to raise the surface dust in the global storms. However, a major difference between Mars and Earth is that tidal winds are not very important in the terrestrial troposphere, but they are an essential feature of Martian meteorology.

The weather systems in the middle latitudes of the Earth are a product of the global circulations. On a rapidly rotating planet heated more at the equator than the poles, coriolis forces give rise to westerly winds at higher levels. If the equator to pole temperature gradient is large, these strong zonal winds develop wave-like instabilities with which are associated high and low pressure weather systems. These instabilities are more intense in winter than summer because the temperature con-

trast between equator and poles is greater at the winter solstice.

How does the Martian atmosphere behave? The winter hemisphere conditions are similar for Mars and the Earth, so we expect similar circumstances to prevail. Indeed, during the Mariner 9 mission, at a time near to the northern winter solstice, parallel bands of clouds were seen moving south-eastwards at 500 km/day developing an east-west orientation at 41 degrees north. This behaviour, and the appearance of the clouds, are similar to a terrestrial cold front. The planetary weather systems may differ in the summer hemisphere. The axial tilt of both allows, at the solstice, slightly more insolation in the summer polar regions than at the equator. The relatively dense and cloudy terrestrial atmosphere provides a high reflectivity in the polar regions so that less solar radiation actually reaches the ground at the poles than the equator, even in mid-summer. But, for the transparent Martian atmosphere the reverse gradient may exhibit itself. The prevailing winds are then easterly, and light, with the absence of the usual planetary waves and little in the way of weather. The dominant wind systems should then be the tidal winds, which is precisely the situation found in the initial Viking surface observations made during the northern summer.

Although, the Martian atmosphere is thin, it does possess layers of condensate clouds, which serve as tracers and modificators of the weather systems. Earth-based observations and the early space missions had indicated the presence of bright patches in certain regions of the planet, such as in the Tempe ridge. But there was little evidence to suggest that Mars could possess such a rich variety of cloud types and activities that have now been identified.

Water-ice clouds have been observed at levels as high as 50-60 km above the surface of Mars during the Mariner 9 mission. Clouds have also been found at about the 0.02 m bar level which is a comparable pressure level at which noctilucent clouds form in the Earth's atmosphere. Examples of lee wave clouds, convective roll systems, and layer clouds have all been observed in the Martian atmosphere.

The most prominent condensation clouds are seen poleward of 45 degrees in each hemisphere and these observed diffuse brightenings are known as the north and south polar hoods, respectively. They occur regularly in the period between winter and spring equinox. The Viking measurements have shown that the atmosphere over the residual northern polar region is saturated with respect to water vapour. Therefore, as the season progresses towards the cooler winter period, we may expect water vapour clouds to form in these regions. Consequently, it would seem that the clouds in the polar hood regions are composed of H_2O ice.

The influence of topography may be the cause of cloud formations near the summits of some volcanoes, and the Viking pictures of clouds around Olympus Mons are a striking example. Certainly there is no need, nor any evidence to postulate that the volcanoes are active, to explain these observations. These clouds are believed to be water ice since the temperatures are not low enough for condensation of carbon dioxide. Both orographic uplift and afternoon convection may contribute to these cloud formations. Since these features form in the vicinity of volcanoes, there may be local degassing of water vapour from the surface layers.

In spite of its thin atmosphere, Mars clearly exhibits some fascinating meteorology with some similarities and interesting differences from terrestrial weather systems.

6. *Local and Global Dust Storms*

Flaugergues suggested that ochre-coloured veils were the cause of certain observations of Mars during the period of 1796 and 1809, and his observations may be the earliest record of the yellow clouds or storms. Though they have been reported at all Martian seasons, global disturbances only seem to occur during the late spring and summer in the southern hemisphere. They appear when Mars is near perihelion and when the diurnal track of the subsolar point on the planet has reached its maximum southern latitude of 24 degrees. The clouds seem to germinate in specific areas in the southern hemisphere such as the Hellaspontus, Noachis, and Solis Lacus regions, which are

known to be elevated plateaux situated between 20 and 40 degrees south latitude.

In recent years, major storms have occurred in 1956, 1971 and 1973, lasting for periods of 3-4 months. Fortunately for atmospheric scientists, Mariner 9 went into orbit around Mars and the Soviet Mars 3 spacecraft landed on the planet during the 1971 storm. These observations have provided us with a wealth of information from which we have been able to develop some understanding of this strange phenomenon.

The development of the planet-wide storms seems to follow a well-defined pattern. In the initial phases lasting about five days, the storm appears as bright spots or cores with diameters of less than 400 km which undergo some diurnal regeneration and overnight decay. The storm then appears to grow, initially in an east-west direction, while blue-white peripheral clouds may appear. Secondary cores may also develop at new locations during this phase of the storm which may last for a period of 5 to 20 days. In 10 to 20 days, the planet is encircled and planetary obscuration occurs in 20 to 30 days in the cases when this stage is reached. The lifetime of the storm will vary according to the meteorological conditions which prevail at the time, but when it begins to decay, the clearing is first noticeable over the polar regions and the high volcanoes.

But why should the thin Martian atmosphere exhibit the violent change in its local meteorological pattern? What special conditions trigger these storms? The Martian atmosphere does, of course, possess a background level of dustiness with the maximum dustiness occurring during the southern spring and early summer. Indeed, the pictures taken from the surface of the planet show a pink rather than a blue sky, confirming this result. The blue sky of the Earth's atmosphere is caused by the Rayleigh scattering of sky light by the air molecules. On Mars, there is insufficient air density for there to be an appreciable Rayleigh scattering. However, the dust particles of about 0.1 μm in size suspended in the Martian atmosphere scatter the incident sunlight at longer wavelengths than any air molecule, which accounts for the pink sky we observe on Mars. The dust particles are highly absorbing, composed of a 50 ± 10

per cent SiO_2 content of the Martian surface material, which is further evidence for a geologically active and differentiated planet.

The global distribution of light albedo markings which trail from craters and other topographic obstacles are a direct indication of wind-blown dust on Mars. Strong local winds generated by the huge elevation differences and the short radiative time constant indicate that the threshold to raise the dust from the surface of the planet may often be exceeded. The strong mid-summer solar heating will cause global scale winds of sufficient magnitude for this purpose. The initiation of the storm may be due to the superposition of one or more additional wind systems on top of a meridional circulation which is already strong. Since the north-east portion of Noachis is a favoured region for storm generation, the topography of that region is probably an essential ingredient. The large temperature difference of about 80° K between the retreating polar cap and the adjacent ground would produce a local mechanism for increasing the level of atmospheric dust at this time. Dust devils and local cyclonic dust storms, familiar properties of terrestrial desert regions, are expected to be ubiquitous on Mars, and they would serve as mechanisms by which low levels of dust could be created and maintained in the southern hemisphere. The strong solar heating of a local dust pall in the presence of weak cyclonic swirl or vertical motion may create horizontal temperature gradients which then induce strong vertical motion. This is a type of 'dusty hurricane'. Heating rates as large as 25° K/day can exist when dust is lifted off the Martian surface and into the atmosphere. There is then a strong feedback between the increased atmospheric heating and the wind systems. Through the hurricane mechanism, the dust heating produces high wind speeds which raise more dust and give rise to further atmospheric heating. As the storm continues, dust will gradually fill the atmosphere over a wide area, remove the horizontal temperature gradients and then cause the storm to decay.

Hopefully, a dust storm will occur during the extended portion of the Viking mission which will help us to refine our

understanding of the mechanisms involved. But there is little doubt that the Martian dust storms are a violent meteorological phenomenon.

7. *Mechanisms for Climatic Change on Mars*

As a more comprehensive picture of the Martian environment starts to emerge from the wealth of scientific data obtained from the recent space missions, we are still faced with providing an answer to the fundamental question; has running water ever existed on the surface of the planet? Although the erosion by a flowing liquid seems to be a natural explanation of many of the large and braided channel patterns observed by Mariner 9, the present atmosphere with a surface pressure of only about 6 m bar, is far too tenuous to permit liquid water. All the water presently on Mars must therefore be in the form of ice or vapour.

The Viking images show examples of tear-drop shaped features that are unmistakenly ancient islands in sky stream beds, water sculpted terrain, and water lines along the shores of the channels. Their geomorphology would suggest that the channels have been cut by a fluid agent, and it is difficult to suggest an alternative to liquid water. Other images show channels that seem to emerge from the head walls of canyons just below regions of collapsed terrain. It is thought that these channels could be caused by slow seepage of underground water or wholesale melting of subsurface ice, which causes the collapse of the region where the water originated.

Volcanic eruptions or meteorite impacts are possible mechanisms for the sudden release of large quantities of water. At least a dozen large volcanoes are quite prominent on Mars, and the amount of water released from them and the craters is of the correct order of magnitude to explain the channels. If a large quantity of water were suddenly injected into the atmosphere it may stay there long enough to spread over the planet and rain out leading to widespread channel formation. But it is difficult to precisely estimate the ages of these volcanoes, and the current views range from 100 million to 1000 million years. Also, there is no current agreement on the ages of the channels,

although it is not thought they were all formed at the same time, but at intervals greater than 10^7 yrs. The best measure of channel ages is obtained from crater counts, which requires a statistical approach that may not be reliable until a large number of regions are analysed by the high resolution Viking images.

Now there is little to debate about the aqueous environment of Mars, for Viking has found water in abundance in the neighbourhood of the poles and the mid latitude channels. We have seen that the northern polar cap may harbour a deep reservoir of water, while further quantities may be stored in the broken surface of the planet in the form of ice or permofrost. Certainly then, it would appear that the fracturing of the regolith by meteoritic impacts could indeed make the water permeate to the surface. Furthermore, it will be important to determine whether the polar reservoir of ice acts as a source or sink, over periods greater than a Martian year for the atmospheric vapour during this phase of the present epoch.

But has the Martian atmosphere been thick enough in the past for large quantities to flow on the surface? Could such a situation happen again in the future? We have already seen from the isotopic inventory, and in particular the measurement of nitrogen (Table 4), that the ancient Martian atmosphere may have had a surface pressure as great as the Earth's current value of 1 m bar. While this situation certainly meets our requirements, could the Martian atmosphere even increase again from its current tenuous state?

Observations of the layered deposits in the polar regions of Mars suggest evidence of climatic change on the planet. These laminæ appear to be unique to the polar region, extend from both poles to about 70 degrees latitude and seem to consist of layers of approximately uniform thickness. Each individual layer may be no more than 50 m thick. What are the processes which form these laminæ? Since the laminated terrain is unique to the polar regions it suggests a meteorologically controlling mechanism. The residue polar caps are now known to be water ice, although, the seasonally varying caps will contain deposits of carbon dioxide also. Direct evidence of the

atmospheric feedback on to the winter polar cap was obtained during the Viking meteorological measurements made from the surface of the planet. The decline in surface pressure recorded on the northern hemispheric site in the Chryse basin was a direct result of carbon dioxide being deposited at the south pole. The atmosphere-cap interaction would appear to be the controlling mechanism for seasonal variations of the surface pressure. As a result, the complete caps will contain a mixture of volatiles such as carbon dioxide, water and non-volatiles such as silicate dust deposited during the dust storms.

How can these volatiles be released into the atmosphere? There are three important cyclic changes in a planet's movement which combine to produce a variation in the amount and distribution of solar radiation incident upon the planetary disk, but without affecting the integrated flux of heat received by the whole planet in a course of a year. They are the changes in the eccentricity of the orbit, the obliquity of the axis of rotation and the precession of the longitude of perihelion, Table 6, first discussed by Milankovich as an attempt to explain the timings of the terrestrial ice ages. Although the variation in the terrestrial parameters may appear small compared with those for Mars, they still provide large variations in the radiation. For example, 10,000 years ago the eccentricity was 0.0190 (now 0.0167), the longitude of perihelion 102° (249°) and the obliquity 24.22 (23.45°), which caused a 7 per cent increase in the solar radiation for the northern summer solstice with a 3 per cent increase in the annual radiation at the poles. These changes in the incident radiation may have resulted in the surface temperature at the earlier epoch being higher than now by a degree or more globally. Since there now seems little doubt that these astronomical perturbations to the Earth's radiation are responsible for initiating the advance and retreat of the terrestrial ice ages, this is a reassuring calibration before applying these ideas to Martian environment.

The obliquity of Mars is highly variable with extremes of 15 degrees and 35 degrees occurring over time periods of about 10^5 years (Table 6). During these extremes the yearly insolation

TABLE 6 Astronomical Factors Related to Climatic Change

	Earth	Mars
Obliquity		
Current value (°)	23.4	25
Variability (°)	±1	±10
Period (years)	4×10^4	1.2×10^5
		1.2×10^6
Eccentricity		
Current value	0.013	0.09
Variability	+0.04	+0.03
	−0.1	−0.07
		10^5
Period (years)	10^5	2×10^6
Precession of the longitude of perihelion (years)	2.1×10^4	1.75×10^5

at the poles of the planet may vary by over 100 per cent. These obliquity variations of Mars are therefore large enough to have important climatic implications, since it would then heat up the poles and surface and release into the atmosphere any volatiles they contain. It had previously been thought that additional carbon dioxide was stored in the polar caps. The knowledge that the residual poles of water ice is a setback to rapidly increasing the thickness of the atmosphere, and therefore the surface pressure, by this method, since water vapour is a less effective constituent for this purpose compared with carbon dioxide. However, there may well be sources of carbon dioxide in the regolith at a depth of a kilometre or so below the surface layers, which may then be released into the atmosphere through the additional heating induced by the changes in the Martian 'astronomical parameters'. Certainly, then, Mars must have a very variable climate. The precise magnitude of the future surface pressure variations on Mars is currently not known and the possibility of the atmosphere being sufficiently thick for water to run freely on the surface remains an exciting speculation.

Summary

The recent space missions to Mars, and Viking in particular have reshaped our knowledge and thinking of the atmosphere of Mars. The isotopic inventory provides direct evidence that the planet once had an Earth-size atmosphere with a surface pressure that may have reached 1 m bar. Under these conditions, the deep dusty basins would have the Martian seas. Water has certainly run on the planet to cut the channels which seem to be typical surface features at some localities. The polar caps may be reservoirs for this water, while amounts may also be locked up in the surface material.

At this time, Mars has a tenuous atmosphere which is only 1 per cent as dense as the Earth's. However, it is dramatically active with meteorological phenomena resembling features seen in the terrestrial atmosphere, and at the same time possessing its own brand of violent storms in the form of the global dust storms which shape the surface and modify the atmospheric environment.

Mars today is cold and the atmosphere is too thin for liquid water to flow on the surface. But this may be a temporary state, since there is no doubt that the planet has a very variable climate, with far greater extremes, than we will endure on Earth. We still have a great deal to learn in order to obtain a complete understanding of our planetary neighbour and future missions to the planet have been stimulated by the data obtained during the Mariner 9 and Viking missions. These encounters have shown Mars not to be a dead planet, but geologically, meteorologically and just conceivably biologically active.

Acknowledgements

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Neutron Stars

S. JOCELYN BELL BURNELL

Ten years ago the most dense, compact type of star known was the white dwarf. The tiny, faint companions of Sirius and Procyon were the first stars found of this kind. They are old stars that have exhausted their nuclear fuel and subsequently contracted under the force of gravity. The matter of which they are made is not normal matter such as we are familiar with here on Earth. All the things we are familiar with consist of atoms, which in turn consist of a nucleus, which is very small and dense, surrounded at some distance by electrons. In a white dwarf star the outer structure of the atom has collapsed under gravity and no longer are the electrons well spaced around the nucleus, keeping apart the nuclei of separate atoms; the nuclei are closer packed than one would normally expect. A white dwarf of the same mass as the Sun would have a diameter about thirty times smaller than the Sun and would be so dense that a matchboxful of it would weigh a ton.

Undaunted by the bizarre nature of white dwarfs, some theoreticians had speculated in the nineteen-thirties about collapse under gravity to even greater densities and to even more peculiar forms of matter. They suspected that if white dwarf material were compressed still more the positively and negatively charged particles in the atom (the protons and electrons) would combine to form neutrons—uncharged particles, a number of which are found in the nucleus of every atom. They thought that this should be a stable form of matter. Thus, the white dwarf material would be turned into pure neutrons, the density of this matter being some ten thousand million times greater than that of the white dwarf.

Might there be stars made of this peculiar stuff, almost pure neutrons? Some astrophysicists thought that such neutron stars could exist, perhaps being formed in a supernova explosion, but since they would be extremely small and well-nigh invisible little attention was paid to the idea. Until 1967/8.

Pulsars

Thirty-odd years after this prediction a new radio telescope which I operated at the Mullard Radio Astronomy Observatory at the University of Cambridge inadvertently stumbled upon neutron stars. We were meant to be observing quasars, and were doing a systematic survey of the sky (or that part of it visible from Cambridge) picking out cosmic radio sources that showed rapid fluctuations—a form of twinkling. Because quasars have smaller apparent diameters than most other categories of radio source they should twinkle strongly. The telescope was also suitable, it turned out, for discovering pulsars—radio sources that emitted their radiation in pulses or flashes, typically at a rate of one pulse per second or half-second. We established that the sources of the pulses were outside the Solar System, but inside our galaxy, so that we were dealing with some sort of star; but this rate of one per second is uncomfortably fast for a conventional star, and difficult even for a white dwarf. As the data on these pulsars accumulated some key facts emerged. The pulse periods were very accurately maintained (comparable with the accuracy of an atomic clock in some cases): and the rapid fluctuations implied a very compact source, perhaps only a few kilometres across. A star could only maintain an accurate pulse period if it had large reserves to draw on, so that frequent emission of pulses did not appreciably deplete its store of energy and cause it to slow down. This implied a star of large mass.

It is now realized that the radio pulsars are neutron stars—for neutron stars are both massive and very compact. The pulsing, or flashing, is believed to be due to the rotation of the neutron star, there being one pulse per revolution of the star on its axis. There is still no agreement about the exact way the pulse is produced: some astronomers favour the existence of a

hot spot of some description on the surface of the star—each time this spot revolves we get a flash of radiation. Other astronomers point out that the neutron star will have a large magnetic field rotating with it and carrying around with it any material there may be at the surface of the star. Some distance away from the surface of the star this co-rotating material and magnetic field will be travelling at large speeds—speeds close to the speed of light. In regions such as this, relativistic effects are important and could concentrate radio emission into a beam. Whichever version is correct, the net result is that the neutron star behaves like a lighthouse, swinging a beam of radio emission around the sky several times a second. Each time the beam sweeps across the Earth we get a pulse.

There are about 150 pulsars known today, and their periods range from 0.03 seconds to 4 seconds. They all emit radio pulses—that is how they have been found—but two of them emit pulses in other parts of the electromagnetic spectrum as well. It is probably no coincidence that these are the two fastest pulsars. In the centre of the Crab Nebula is the fastest pulsar of all—rotating some thirty times a second. From this pulsar flashes have been detected at optical wavelengths, at X-ray wavelengths, and at even shorter wavelengths too, in the gamma-ray region. The second fastest pulsar, in the constellation of Vela in the Southern Hemisphere, has recently been found to emit gamma-ray pulses; curiously no X-ray pulses have yet been detected from it, but optical astronomers in Australia identified it in early 1977.

Binary X-ray Stars

X-ray astronomy is one of the newer branches of astronomy; it is technically difficult because the Earth's atmosphere screens us from the X-rays from space, so all X-ray astronomy has to be done with telescopes flown high on rockets, satellites or balloons. The first X-ray astronomy satellite was launched in 1970, and amongst the sources it discovered and studied there were some particularly intriguing ones in the Milky Way which showed periodic variations in their X-ray emission. The source known as Centaurus X-3 (the third X-ray source

identified in the constellation of Centaurus) is typical of these. Its X-ray emission is strongly pulsed—about 80 per cent pulsed—and it has a pulse period of 4.84 secs. As well as this there is another period of 2.087 days in the data; for about half a day in every 2.087 Cen X-3 is considerably weaker (by a factor 10) than it is for the rest of that period. The 4.84 sec pulsation cannot be detected on these half-day holidays! To further confuse the issue, sometimes the source remains invisible for weeks at a time, when neither the 4.84 sec nor the 2.087 day periodicities can be seen. Careful examination of the 4.84 sec pulsations revealed that the period actually changes, ranging from 4.83 to 4.85 sec, and this change was also cyclical, with a period of just over two days!

To date there are about a dozen X-ray sources which show this sort of behaviour: their pulsation periods are between one second and several hundred seconds, while the other, longer periods are in the range one to ten days. These sources are believed to be binary systems in which a large B star (a blue supergiant) and a neutron star orbit each other. The two stars form a particularly close pair, and the gravitational pull of the neutron star distorts the supergiant and pulls material off it (at a rate of 100 million million million tons per second). This accretion of material by the neutron star is the key to the X-ray emission which arises when the material is funnelled down on to the neutron star's surface by its magnetic field. The binary system has an orbital period of several days, and once per orbital period the neutron star (and X-ray emission) is eclipsed by the supergiant. The period on the time scale of seconds is the rotation period of the neutron star—as in the radio pulsars we receive one flash per revolution. The small cyclical changes in the X-ray pulsation period are the Doppler shifts produced by the orbital motion of the neutron star around its supergiant companion. This tidy picture is spoilt by the anomalous lows—the days or weeks when no X-ray emission is detectable from the source. These phenomena are believed to be due to changes in the rate at which material is accreted from the large star by the neutron star, but it is not clear whether there is a halt in the accretion and therefore no X-rays, or whether there is an

increase in the accretion and no X-rays because the extra material around the neutron star absorbs them.

Supernovæ

Supernovæ are cataclysmic explosions which mark the death of some larger stars. When they occur in that part of the Milky Way close to us they are very spectacular—the exploding star may become as bright as the full moon, and be visible in the day-time for days or weeks, then gradually fade. Astrophysicists have estimated that on average there is a supernova explosion in our galaxy once every 50 or 100 years, but as luck would have it, one has not been seen since 1604 (shortly after the death of Queen Elizabeth I, and before the invention of the telescope!)

A supernova does not occur until the star has used up much of its available nuclear fuel, so in that sense it is an old star, but because these stars are big and massive they burn more rapidly and more quickly reach their dramatic end. Much of the star is blown off in the supernova explosion but the core of the star remains, and it is this core that in the explosion becomes compressed to form the neutron star.

However, we may soon have to consider other methods of forming neutron stars. Although only 150 pulsars have been detected so far, there are estimated to be 100 thousand or a million active pulsars in our galaxy. Each has a life expectancy of some million years before so much of its rotational energy is used up that it can pulse no more. If these estimates are correct, then there would have to have been, on average, one supernova explosion every ten years in our galaxy. Perhaps neutron stars can be formed quietly—perhaps the contraction which must occur when a star runs out of nuclear fuel and ceases to shine can proceed steadily without the outburst of energy which causes the supernova.

The binary X-ray stars have probably also been through a supernova stage, but here the picture is more involved because there are two stars to consider. A probable scenario looks like this: in the beginning there is a binary system consisting of a large star and a very large star. The very large star evolves

rapidly and after a million years or so has used up its fuel and explodes as a supernova forming the neutron star. Its companion which has been evolving more sedately now finds itself sharing life with a very compact neutron star, and instead of being the smaller star in the binary, it is now the larger—by far. At this stage we have the typical X-ray binary described above. What stages might follow? In the immediate future the neutron star will quietly accrete material from its larger partner which must, of course, be evolving itself. As this evolution proceeds the rate of transfer of material to the neutron star varies—the variation will probably show up as changes in the rotation rate of the neutron star, and as changes in the X-ray brightness. Ultimately, the larger star will have burnt up all its nuclear fuel and presumably will go through a supernova stage to form a neutron star. Provided this explosion does not disrupt the binary system, we would then have two neutron stars orbiting each other.

The Binary Pulsar

One astrophysicist has estimated that about 1 per cent of all pulsars should be in such a binary system. He made the prediction when 110 pulsars were known, and soon after that the first binary (radio) pulsar was found. This pulsar, known as PSR 1913 + 16, was first detected in July 1974, and found to have a period about 59 milliseconds (59 thousandths of a second). Most pulsars change their periods slowly, by a few millionths of a second per year, as the neutron star loses rotational energy. But this pulsar wouldn't keep steady. It changed its period by up to 80 millionths of a second per day, and sometimes by as much as 8 millionths in five minutes! The explanation was in terms of a binary system, but a surprisingly fast binary, with an orbital period of about eight hours. This implies that the two components are very close together and if the other companion was an ordinary star like the Sun then the neutron star would be skimming its surface. The companion is probably another neutron star.

As well as implying that our ideas about stellar evolution are broadly correct, this binary pulsar will be a useful check of

relativity theory—according to that theory the orbit of the binary should show precession (just as the orbit of Mercury is predicted to show precession); the precession should be about 2 degrees per annum.

The Structure of a Neutron Star

Apart from noting that neutron stars are orders of magnitude more dense than white dwarfs and that they are composed largely of neutrons we have said little about what a neutron star actually is. Its mass is probably about the same as the mass of the Sun, but its diameter is only 20 kilometres (about 12 miles), so that it would fit comfortably within the boundaries of many of our cities. This mass concentrated in such a small volume means very large densities—on average 100 million million times as dense as water, or a thousand million tons per cubic inch. A pin's head made of this material would weigh more than the QE2.

The neutron star probably has a solid crust, a liquid interior and perhaps a solid core. In some ways it resembles a raw egg—a thin shell on the outside and some peculiar fluids inside. The neutron star crust is relatively normal (note the 'relatively'). The density is only a million times that of water, and the crust is crystalline—mainly of iron. But not atomic iron—all the electrons have been removed and it is nuclei of iron atoms which are close packed.

Inside the crust the density is greater and the substances more exotic. The next region, the mantle, is a fluid, made up of neutron rich materials. Here on Earth nuclei of atoms contain approximately equal numbers of neutrons and protons, and the largest nuclei which are stable have about 100 protons in them; above this number for some reason the nucleus breaks up. But in the neutron star mantle the number of neutrons is much greater than the number of protons, and nuclei with up to 140 protons are believed to be stable. The density in this region is about 1,000 million times that of water.

Within the mantle is a superfluid core—a fluid almost entirely of neutrons, with a few protons and electrons around. This fluid has zero viscosity (there is no resistance to flow) and

is perfectly superconducting (there is no electrical resistance).

What is inside this core is rather conjectural. Physicists do not yet understand the behaviour of material at very high densities and pressures. Perhaps the neutrons break down into even more fundamental particles—possibly the particles called hyperons, things like the Σ^-, Λ°, Δ particles. This part of the neutron star has been described as 'a rich Greek alphabet soup'. Or perhaps at its centre the neutron star is a quark star. Quarks are particles that supposedly come in threes and have charges one-third or two-thirds of the electron's charge. They have been named after a phrase of James Joyce's 'three quarks for Muster Mark'. They have not yet been found to exist, although they have been searched for, so perhaps it is also appropriate that in colloquial German quark means nothing, or rubbish!

The gravitational force around a neutron star is very strong—objects on its surface would weigh ten thousand million times what they do on Earth. If there were the slightest wrinkle on the surface of the star the work one would have to do to get over it would be comparable to the work done climbing Everest. The gradient of the gravitational force is also much greater near a neutron star than it is near the earth. This means that if you went close to a neutron star there would be an appreciable difference in the gravitational forces on different parts of your body; your feet would feel a much stronger pull than your head for example, and the difference would be sufficient to pull you apart. Even curling up tight in a ball would not save you.

As well as the strong gravitational field there is a strong magnetic field. It is believed to be about a million million gauss. To appreciate how large this is remember that the Earth's magnetic field (which is used in navigation by compass) is about one-third of a gauss. The largest magnetic field man can make is a few million gauss, and that can only be kept up for a fraction of a second. It is this enormous field that plays a crucial role in the production of the radio and X-ray pulses from neutron stars.

In Conclusion

All this sounds like science fiction, so incredible are these neutron stars. But regardless of the difficulty we may have in taking in the peculiar properties of these stars, they are here to stay, and astronomers are learning to live with them and to learn from them. Since the discovery of neutron stars fresh interest has been taken in the physics of matter at very high densities: there has been study of the atmosphere of neutron stars, the way in which they accrete material, and the way in which they radiate: and there has been more study of supernovæ, where they are supposed to originate. There has been one other development in which neutron stars have played a large part, and this is because astronomers now ask themselves: if neutron stars exist, can even more compact, dense bodies exist? What happens if collapse under gravity continues beyond the neutron star stage? This has lead to the study of black holes, and compared with those of black holes, the properties of neutron stars look conventional!

Extragalactic Nomenclature – A Simple Guide

SIMON MITTON

The past few years have seen a considerable growth of interest in active and unusual galaxies, in addition to the widely publicized studies of quasars. There are several reasons for this burst of activity. The completion of several large telescopes, especially the 4-metre series now operating on Kitt Peak, in Chile, and in Australia, have spurred on researchers. Many of the peculiar galaxies are faint objects, due to their relatively large distance from the Milky Way, and hence a big telescope is essential for detailed studies. Another technological development has been the introduction of electronic, as opposed to photographic, techniques for the acquisition of data. For example, the instrumentation attached to a telescope such as the Anglo-Australian Telescope is much more efficient than would have been the case a few years ago. One remarkable invention of great value to spectroscopists has been the electronic spectrum scanner; these devices enable the background light of the sky, containing auroral and streetlight contamination, to be subtracted from the signal received from a star or galaxy. Since the night-sky emission lines are often stronger than galaxy or quasar emission lines the benefit to astronomers of sky-subtraction is very considerable. Added to these improvements in hardware has been the discovery of a great variety of phenomena in the extragalactic universe, all demanding careful observation and critical theorizing. Since the most energetic and the most remote objects tend to be abnormal it is hardly surprising that a significant fraction of the usable time on the new telescopes has been allocated to those specializing on active galaxies.

Rather like the botanists and stellar spectroscopists of a century ago, extragalactic astronomers like to be able to classify the objects that they look at. And, again like the botanists, terms are often invented before the true nature of a new object is fully understood. An unfortunate consequence for the amateur astronomer interested in galactic research is that there now exists a bewildering array of terms that are meaningless except to the experts. Common names such as Markarian galaxy or BL Lacertæ object or Type II Seyfert actually convey no information to those not already familiar with the jargon. The confusion is compounded by the fact that some objects are named after their discoverer (e.g. Zwicky and Markarian galaxies) whereas others are categorized by their physical qualities (e.g radio galaxy or high-redshift quasar). In this situation, it is not unusual for an object to end up with two or three labels: some Markarian galaxies are Seyferts, for example.

This lack of discipline in classifying extragalactic objects is not only bewildering when encountered for the first time, but it may even be hindering the progress of research if too much emphasis is attached to giving objects names, at the expense of understanding what makes them work. In those cases where objects are also radio or X-ray sources even more names will apply, because the source of radio emission has to be given an identifying tag before an optical object has been matched to it. Radio sources are frequently named after the observatory where they were discovered, whereas X-ray emitters tend to be named after the satellite carrying the X-ray telescopes. So, 3C 273, is radio source number 273 in the third Cambridge catalogue, and A0620-00 is an X-ray star at right ascension 06 hr 20 min in the Ariel satellite's survey.

To provide a general guide through the minefield of extragalactic nomenclature I have compiled the following brief notes. As new objects are found the boundaries between categories become less rather than more sharply defined. So there is a certain arbitrariness in the definitions and they probably will not agree exactly with those found elsewhere—there is more than one route through the minefield!

First of all I want to deal with some of the objects that are named after people.

Zwicky compact galaxies were found by the astronomer Fritz Zwicky while working on Schmidt photographs of the deep sky. They are barely distinguishable from star images on the sky surveys. At first Zwicky circulated his lists privately, but they were later published. I Zw 1 denotes the first object listed in the first list (list I) and so on. In general, they are compact galaxies with a high surface brightness.

Seyfert galaxies were first classified as a group by Carl Seyfert in 1943. They are spiral galaxies with brilliant nuclei and inconspicuous arms. The light from the nucleus has many emission lines of ionized gas. It is now known that the Seyfert galaxies are relatively common and the use of the term no longer indicates only objects given in Seyfert's original list. As a class they are subdivided into Type I and Type II. In the former category the lines of hydrogen in the spectrum have a much greater width than lines from the ionized metals, whereas in the second category they are of about the same width. If the spread of the line is interpreted as Doppler shifting, then the spread of velocities is thousands of kilometres per second in Type I Seyferts, but only a tenth of that in Type II. Many Seyfert galaxies are also radio sources, the most famous being NGC 1275 in the constellation Perseus, which is associated with the radio source Perseus A or 3C 84 and which is also an X-ray object. Another notable feature of the Seyfert galaxies is that they exhibit short-term fluctuations in the optical and radio outputs. This indicates that the active heart of some Seyfert nuclei cannot be more than a few light weeks in diameter.

Markarian galaxies are named for the Russian astronomer, B. E. Markarian, who used a Schmidt telescope with a prism in front to net large numbers of objects with unusual spectra on a single photograph. A similar technique has been used very successfully on the UK 1.2-metre Schmidt telescope in Australia. Markarian's survey picked up many Seyfert galaxies as well as irregular and disturbed galaxies.

Haro galaxies are essentially similar to Markarian galaxies,

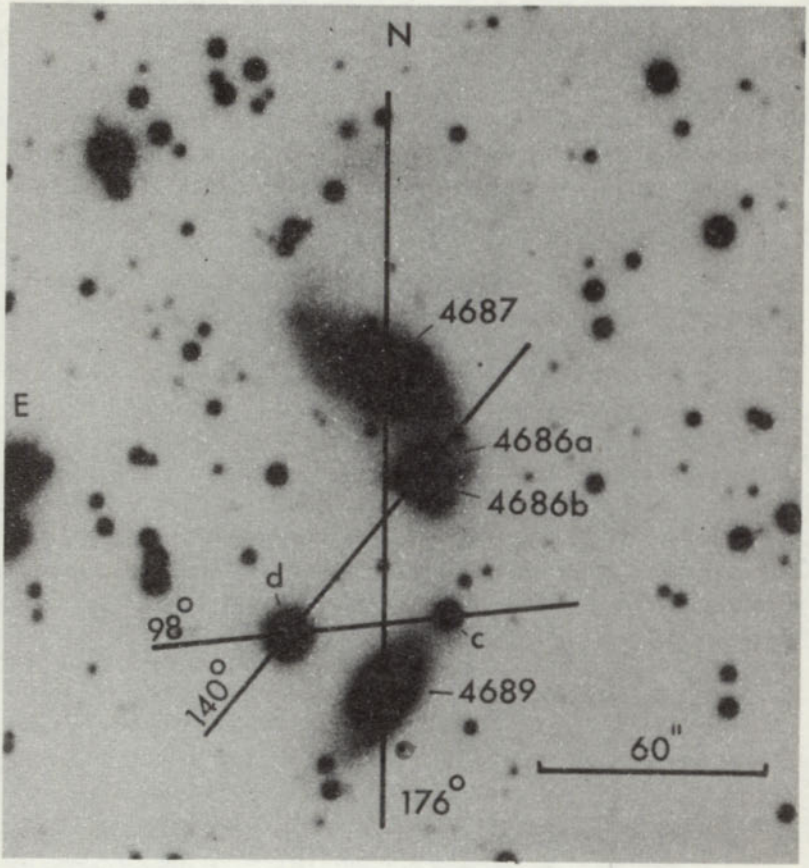

Figure 1. A group of interacting galaxies photographed with a l-metre telescope at Las Campanas in Chile. The numbers refer to the IC catalogue of nebulæ. IC 4687 may well be a type II Seyfert galaxy. IC 4686 has two compact nuclei that show emission lines. The system is embedded in a gaseous envelope. The entire group is unique and needs further investigation. (European Southern Observatory)

except that they were found in the southern sky by Haro, working at the Tonantzintla Observatory.

In summary, it is only necessary to note that Zwicky, Markarian and Haro galaxies refer to objects in particular published lists, whereas Seyfert galaxies refer now (although

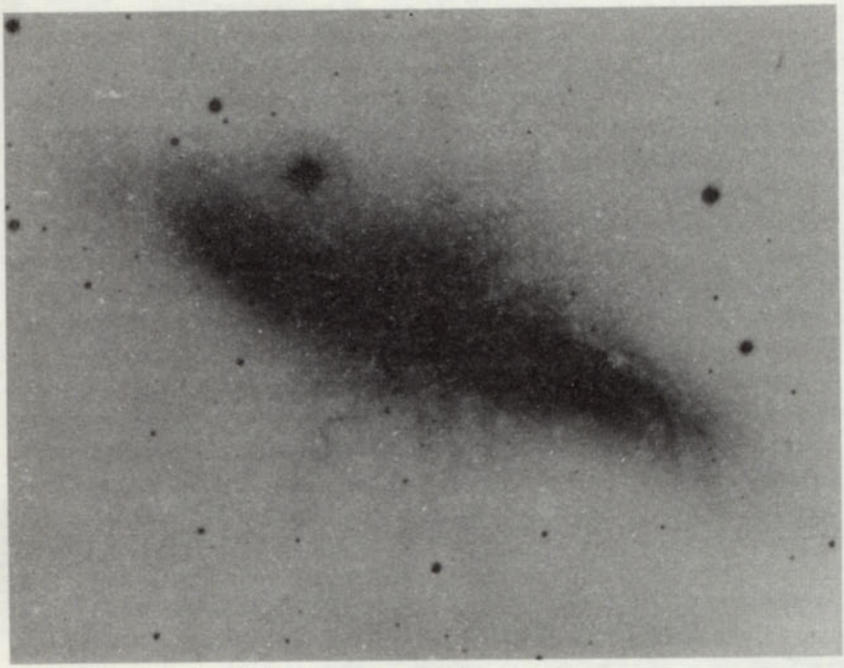

Figure 2. The disturbed galaxy M82, which gives the appearance of having suffered a violent explosion. (Hale Observatories)

not in 1943) to particular physical types. I now want to mention those galaxies with a descriptive name.

Exploding galaxies really do seem to be objects that have been overwhelmed by a nuclear catastrophe in the recent past. Perhaps the best known example in M82, the visible part of which consists almost entirely of ejecta thrown out 1 to 10 million years ago. This object is also a strong radio emitter as well as an infrared source.

N-type galaxies have almost all their luminosity concentrated into a brilliant star-like nucleus that is surrounded by faint and compact nebulosity. In many respects they are very like the Seyfert galaxies, and the use of the term N-type seems to be dropping gradually.

Radio galaxies, one of the oldest of the 'new' terms, are

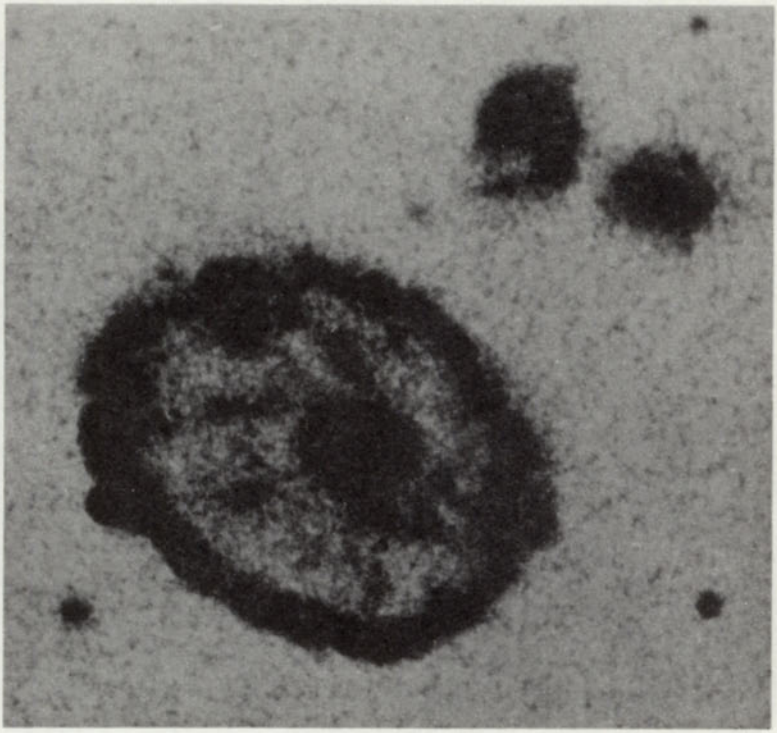

Figure 3. The spectacular ring galaxy known as the Cartwheel, photographed with the UK 1.2 metre Schmidt Telescope. The ring is composed of highly-excited gas. (UK Science Research Council)

galaxies which emit a strong flux of radio waves. The prototype of these objects is generally considered to be Cygnus A which emits a prodigious 10^{38} watts in the radio domain. This is millions of times more than the radio emission from the Milky Way. Cygnus A is a distant 16th magnitude galaxy, visible only in large optical telescopes. The radio emission of radio galaxies generally comes from two elongated lobes symmetrically disposed on each side of the optical galaxy, which gives the superficial impression that energetic material has been thrust out of the galaxy in a symmetrical explosion. The very largest radio galaxies rival entire galaxy clusters in their overall

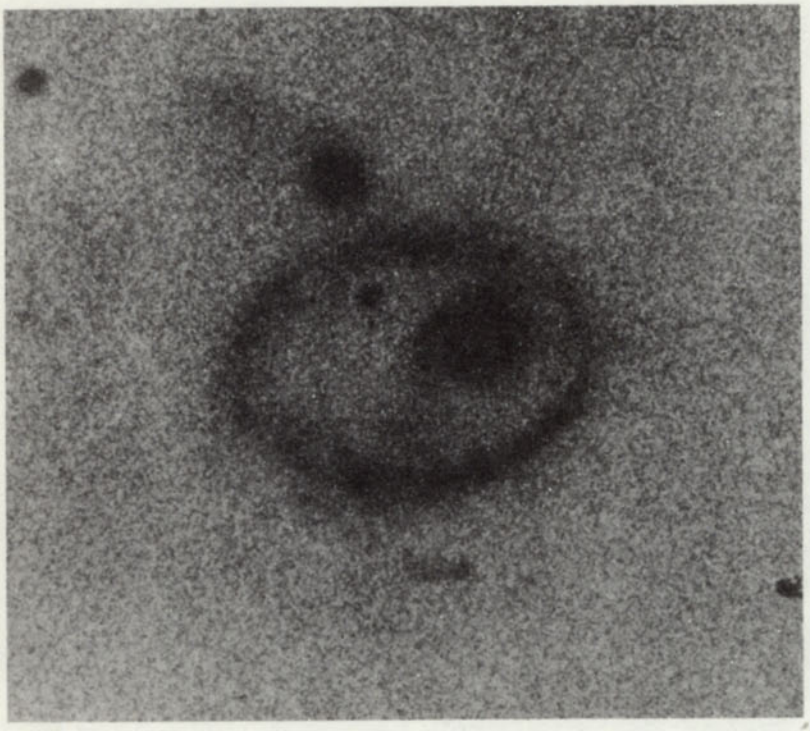

Figure 4. Another ring galaxy, photographed at the Kitt Peak National Observatory in the United States. (KPNO/AURA)

extent. Radio waves are generated in radio galaxies by the synchrotron process: very high speed electrons in the source are constrained to move along curved paths by the internal magnetic fields, and this leads to the emission of electromagnetic waves.

Ring galaxies have an apposite name because they look like rings. These objects have recently come to the fore because many of them have been found in the new series of surveys of the southern sky. Some of the rings have a central nucleus, and in some cases there is a small galaxy near to the ring along its axis of symmetry. It seems likely that a few of the ring galaxies were made when a spiral galaxy collided with a compact

galaxy. This could trigger a burst of star formation and give a ring-like appearance. Other rings may just be spirals viewed from an aspect that makes the arms appear to form a ring. Certainly they are not a homogeneous class of objects and they would merit further study.

Quasars (QSOs) are the most celebrated of the extragalactic oddities; the name is a contraction of quasi-stellar object. The first quasars found were starlike objects coincident with strong radio sources. The optical spectrum of a quasar usually has strong emission lines of substances such as hydrogen, oxygen, magnesium and carbon. The crucial property is that of redshift: in the quasars the spectral lines are found at wavelengths considerably longer than for emission from objects at rest. The redshift is a measure of the change in wavelength relative to the rest wavelength. Quasar redshifts range from about 0.1 up to about 4, with a great many in the range 1.5 to 3. Any object with emission lines, having a compact image on the sky survey, and a redshift exceeding about 0.4 will now tend to be classified as a quasar. A striking discovery of recent years is that some quasars do not emit radio waves at all and others have only absorption lines; hence the redshift is now the single most important quantity for categorizing an object as a quasar.

BL Lacertæ objects (BL Lacs, *not* Lacertids as some extragalactic astronomers unfamiliar with meteor showers will insist on calling them!). The first object in this category to be described was actually the variable 'star' BL Lacertæ. This is actually a radio source bearing similarities to certain types of quasar. In addition, it is optically variable and has a strong polarization. The special optical property of BL Lacertæ objects is that they have a continuous power-law spectrum with no spectral lines or at best very weak ones. Most of the light is probably generated by the synchrotron process in a compact nucleus. Around two dozen BL Lacs are now listed in catalogues. In a sense, they are quasars without any obvious lines in the optical spectrum.

This is the very briefest 'user's guide' to extragalactic terminology. It is useful also to know a little about the various catalogues of radio and X-ray objects. To give a complete

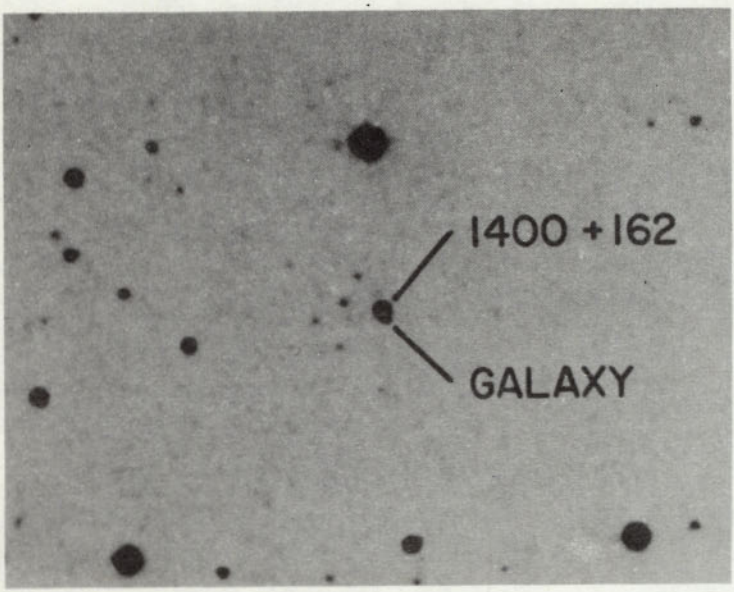

Figure 5. A BL Lacertæ object, 1400 + 162 which is apparently associated with a cluster of galaxies. (Lick Observatory)

listing of these would be long and tedious, so here is a note on the ones mentioned most frequently in the popular literature. Perhaps the one everybody knows is the 3C, or third Cambridge catalogue; there are also 4C and 5C listings. All have been published in either the Monthly Notices or the Memoirs of the Royal Astronomical Society. The very extensive listings from the Ohio State Radio Observatory are preceded by two letters, the first of which is always O. Objects in the Parkes catalogues are denoted by the prefix PKS followed by four numerals giving the right ascension and two giving the declination. Important X-ray catalogues include the Uhuru series, in which the code 2U and 3U precedes numerals giving the position, and the Ariel catalogue, which uses the letter A. Fortunately, observatories are now using a fairly uniform system to refer to newly discovered objects. Instead of assigning a number that gives the position in a list (e.g. 3C 273) it is

now common to give a number that gives the position in hours and minutes of right ascension and degrees and tenths of a degree in declination. Thus, object 1400 + 162 (a BL Lac) is at RA 1600 hours and dec 16.2 degrees. This system makes it much easier to relate the same object in different listings.

Observational and theoretical astronomers are moving closer to a uniform system of extragalactic taxonomy. Increasingly, the evidence is suggesting that there is a unity of the activity in galaxies and quasars. The amount of activity varies from object to object, but the names, which are little more than historical ballast, are tending to obscure this underlying unity. As examples note that in a great many respects the Seyferts can be considered as mini-quasars. And it is especially interesting that the spectra of low-redshift quasars and high-redshift Seyfert galaxies are often identical. If we imagine moving a Seyfert further away it is not hard to visualize that at some distance all we will resolve is the starlike nucleus, so the description would presumably then switch to the term quasar. Equally, some of the N-galaxies would look like quasars if they were only a little further away. Both Seyfert galaxies and quasars show optical and radio variability. Many quasars are indistinguishable with a radio telescope from radio galaxies.

We see then that the properties of the objects thrown into boxes labelled 'Seyfert' or 'BL Lac', overlap to a great extent. How much more sensible it would be to call them all active galaxies, where the term galaxy would be understood to mean system of gas and stars of galactic mass beyond the Milky Way.

Within the active galaxies an energetic nucleus is responsible for much of the observed phenomena. This nucleus probably contains a particle accelerator that is able to boost protons and electrons up to almost the speed of light, where their energies will perhaps be millions of times their rest energy. Various suggestions have been made for the ultimate energy source, and the problem cannot yet be considered as solved. Nonetheless the field is narrowing, and many theorists now favour black holes as the ultimate energy source. A black hole is a region of space in which gravitation is so high that nothing, not even light, can escape. However, as matter falls into the black

hole it is able to release energy as electromagnetic waves under certain circumstances. If these special conditions do indeed prevail inside some galactic nuclei then black holes gobbling up stars and the interstellar medium would be prodigious sources of energy. Alternative ideas have been put forward, such as the hypothesis that the supernova rate might be unusually high inside a nucleus. If true, this would lead to an excess of energy. Even if the black hole model is accepted, however, it is still not known how the released energy is channelled into fast particles, nor how the high magnetic fields present in many objects are created.

We can envisage that energy release from a central source will occur to different degrees in different types of object. Given this, we can now make a first crude attempt at systematizing extragalactic objects. In this picture the BL Lacertæ objects have a strong flux of continuous light from the central source. This light has not excited any nuclear gas in a way that leads to emission lines and so the spectrum is featureless. In the quasars, on the other hand, there is plenty of gas around; this gets excited by the radiation from the black hole's neighbourhood and emission lines result. Seyfert galaxies are sufficiently near that we can still see their spiral arms dimly beyond the brilliant nucleus. Similarly, in the radio galaxies it is possible to discern the underlying galactic structure.

In this general approach we have not accounted for why some objects are funny while others are normal, because we do not know why this happens. Nor do we know how long an active galaxy can remain active. Either most galaxies go through this phase, in which case it is short-lived, or only a few do, but in those where there is activity it lasts a long time. Our instinct in these post-Copernican times is to assume that most objects are active at some stage, but that this must be temporary for most of them. We know that in the past quasars, for example, were more numerous than they are now. So, are there any dead quasars in our vicinity? Again we cannot answer with certainty but there are intriguing clues. Unusual activity takes place in the centre of our own Galaxy: it seems to have thrust out a bit of a spiral arm recently and it is a strong infrared

source. It has been suggested that the galactic centre may contain a small black hole to account for these observations. In the past this black hole could have been much more active than it is now. Perhaps in the future it may get stoked up again if sufficient stars drift too close to its irresistible clutches. So maybe even our own Galaxy has a mini-quasar in its heart.

What's New in the Local Group?

HEATHER COUPER

You could be quite forgiven for believing that beyond the confines of our placid Galaxy, the Universe is a violent place. Super-luminous quasars blaze out from its remotest reaches; giant galaxies, racked with catastrophic explosions, send out distress signals of radio waves. Nearer home, we witness traffic accidents of gigantic proportions—galaxies slowly torn apart by the tremendous tidal power of a close encounter, their stars and gas flung into space in exquisite, convoluted streamers.

But we tend to forget—much in the manner of sensational Sunday newspapers—that the majority of galaxies are quiet, law-abiding citizens. Most are so small and insignificant that they can only be studied close at hand; yet these are by far the most numerous galaxies in the Universe. It is fortunate indeed for our knowledge of normal galaxies that our Milky Way galaxy does not travel the Universe alone. It belongs to a small cluster of galaxies—the Local Group. As well as containing three, or perhaps four moderately large galaxies, the Local Group provides a home for a variety of smaller and fainter objects which would be unobservable if they were more remote. Only by studying our own small neighbourhood of intergalactic space can we get a true idea as to what really makes up the Universe.

Clusters of Galaxies

Clusters of galaxies, like our Local Group, are by no means unusual. Max Wolf identified a number of what he delightfully called 'nests of nebulæ' in the opening years of this century; but the discovery of most clusters had to await the development of

Schmidt telescopes in the early 1930s. At last, it became possible to photograph large fields of the sky—several degrees across—at once; and it was quickly noticed that the distribution of galaxies looked clumpy. Astronomers today believe that over half the galaxies we see belong in clusters, whose member-galaxies are bound together in space by the invisible threads of each other's gravity. So tenacious are these forces that the largest clusters known are vast clouds of hundreds or thousands of galaxies, up to 50 million light-years in extent. These giant clusters uncannily resemble one another; in their size, their roughly spherical distribution of galaxies, and in the limited types of galaxies they contain. For this reason, astronomers call them 'regular' clusters, and study their properties avidly; for these may be the basic 'building blocks' of the Universe.

But what of the smaller clusters, like our own? Such 'irregular' clusters have no particular distinction: they contain a hotch-potch of all galaxy types, from smooth ellipticals to lumpy spirals; there is no preferred distribution of members; and (with a few exceptions) they tend to be on the small side. 'Small' is, of course, a relative term! The Local Group measures some 5 million light-years from edge to edge; but our flattened cluster is clearly not in the same league as the giant, spherical, regular systems. Astrophysicists are currently trying to account for the differences between the two sorts of clusters; but it is a formidably difficult problem, requiring a knowledge of how galaxies form, evolve and interact in large numbers. An agreed picture has yet to emerge.

If clusters of galaxies are common in the Universe, what about clusters of clusters of galaxies? It may seem rather an academic question, but it takes on more relevance when we learn that our Local Group is probably a member of one such 'Supercluster' of galaxies. Detailed studies of the distribution of galaxies and clusters have revealed clumps of clusters up to 180 million light-years across; and the consensus seems to be that these are real physical groupings. Our 'Local Supercluster' contains several other small clusters besides the Local Group—notably the M 81 group in Ursa Major, and the Sculptor

group—all centred on the giant swarm of galaxies in Virgo, 65 million light-years away. However, the matter is not quite settled. Some eminent astronomers believe that the Local Supercluster is completely illusory, a result of the patchy clumping of galaxies. It is of vital importance to find the right answer, for astronomers need to know whether the motion of nearby galaxies is determined entirely by the expansion of the Universe, or modified by the gravity of the Supercluster. But this brings us to problems of cosmology, too remote to be considered here. It is time to return to the comparative neighbourliness of our Local Group.

Our Local Cluster of Galaxies

A distant observer studying our Local Group would hardly consider it worthy of the title 'cluster'. He might believe it to be just a pair of fine, well-matched spiral galaxies, accompanied by a smaller, rather patchier specimen. We ourselves know that the picture is different; but in order to get our bearings, let us briefly meet these important members of our neighbourhood.

The smaller of the pair of spirals is a very special place to us; for it is our home, the Milky Way galaxy. At this point, we need not be too modest, for our Galaxy is a giant of its kind: a great rotating wheel of 100 thousand million stars, measuring 100,000 light-years from rim to rim. Its hub is a densely-packed ellipsoid of old, cool red and yellow stars; and from this spring the spiral arms, threading their way through the Galaxy's disc. But unlike the solid spokes on a wheel, the glorious arms are evanescent. They are merely zones of compression, through which continually changing stars and gas slowly pass, and where star formation is triggered. As we see in other spiral galaxies, the arms are riddled with dust and gas, and studded with hot, young blue stars. It is to one such spiral arm, near the edge of our Galaxy, that the Sun and its planets currently belong; other arms nearby glow in our skies as the luminous band we call the Milky Way.

Although our position in the Galaxy affords us magnificent views of young stars and shining nebulæ, there is one serious disadvantage. Spiral arms are filled with tiny particles of

dust—rather like cigarette smoke—which has the effect of blocking our view if we want to look into the galactic disk. As a result, light coming from the very centre of our Galaxy—and beyond—is dimmed thousands of millions of times. Although longer wavelength radiation, such as infrared and radio waves, can penetrate this murk, we know less about the nucleus of our own Galaxy than we do about others millions of light-years distant. But recently, astronomers have discovered an exceedingly small, powerful radio source right at our Galaxy's heart; and peculiar motions of gas nearby show evidence for a great explosion. Could our now-quiet Galaxy have been through a violent phase in its lifetime? Or are these motions simply telling us that our Galaxy is a barred spiral (with a bar-shaped, rather than ellipsoidal nucleus), as some astronomers believe? It is less perplexing to turn our attention away from the nucleus and into the region of space surrounding our Galaxy.

But we have not yet escaped into true intergalactic space. A huge, near-spherical 'halo' of thinly spread stars surrounds our flat Galaxy, a relic of its very early days when it was a vast cloud of gas. As we would expect, this halo contains the objects which were the first to form—the oldest stars in the Galaxy. Many of these are concentrated into dense balls of thousands or even millions of stars, called globular clusters. We know of about a hundred such globulars in the halo, important historically because they contain RR Lyræ variable stars which helped to fix the scale of our Galaxy. But some have lately taken on a new importance as the sources of intense outbursts of X-radiation—the mysterious 'X-ray bursters', recently discovered by orbiting satellites. Their mechanism is, so far, unexplained; but it seems that there is life in old stars yet!

We have dwelt a long time on our Galaxy, for it is a very typical example and can give us standards to compare elsewhere. But it is time to move away, to cross the void of two million light-years which separates us from what may be the biggest galaxy in the Local Group; the Great Andromeda Spiral, M 31. In every respect, it appears to be a twin of our own Galaxy, but half as large again. Like our Milky Way galaxy, a radiosource marks its heart; its smooth nucleus is

wrapped in the coils of shining spiral arms; and over 300 globular clusters throng its halo.

Not far away from the Andromeda galaxy lies the third major member of our Local Group; the galaxy M 33 in Triangulum. A much smaller, fainter specimen, this; a clumpy little spiral with ill-defined, loosely wound arms. It is only half as large as our Milky Way; but with ten thousand million stars within its bounds, it is by no means a dwarf galaxy.

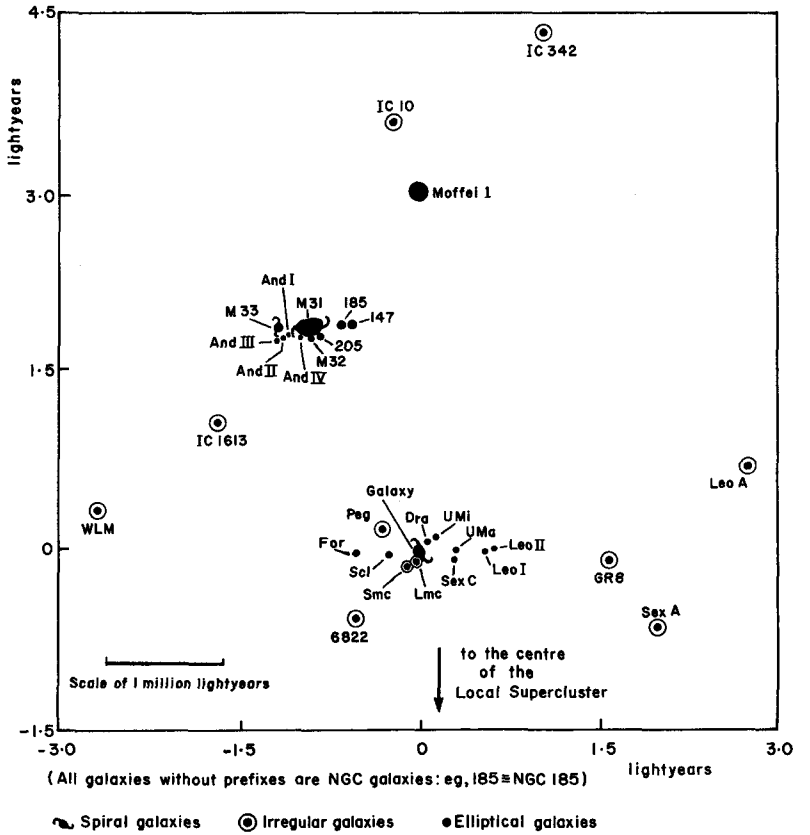

Figure 1. The Local Group of Galaxies.

Galaxies in Miniature

Figure 1 shows how these three major galaxies fit into the Local Group. But you will notice that they have now been joined by a couple of dozen others, bringing the total membership up to about thirty. These are the small, faint galaxies mentioned earlier: the most common sort in the Universe. Just how different are these 'dwarfs' compared with larger galaxies like our own? Let us take a closer look.

Dwarf galaxies come in two sorts, elliptical and irregular; so far, no dwarf spirals have come to light. Most diminutive of all are the dwarf ellipticals—marked as small black circles on Figure 1—made up entirely of old, red stars. Their vigorous days of star formation are over; all their gas has long been used up, and they have settled into sedate old age. Most contain far less than a million stars and scarcely merit the title 'galaxy'; they are hardly more than globular clusters. But it is possible to tell the two apart, for the dwarf galaxies, although containing the same number of stars, are generally ten times larger; which means that their stars are very thinly spread. If we lived on a planet in one of these tiny galaxies, we would see only three stars in our night-time sky!

Not surprisingly, dwarf elliptical galaxies—only 5,000 light-years across—are very hard to find. The majority have been discovered in the last thirty years during special searches around our own Galaxy and the Andromeda galaxy. Their low surface brightness makes them difficult to photograph; a task which is further complicated if they lie behind bright stars in our own Galaxy—such as Leo I and Leo II, which are very close to Regulus. The most recent search around the Andromeda galaxy in 1971 added four new dwarf ellipticals to the Local Group; Andromeda I, II, III and IV. It is possible that Andromeda IV is not even a true dwarf, but a detached portion of the Andromeda galaxy itself.

The ranks of these small elliptical galaxies have been further swelled by a few of their first cousins—true intergalactic globular clusters. These 'Tramp' globulars seem to have escaped from the gravity of their parent galaxies, and now roam the Local Group untrammelled. One globular cluster in

our own Galaxy—NGC 5694—appears to be making such a bid for freedom, travelling away at a speed which is well above the Galaxy's escape velocity. Astronomers believe that the pull of passing galaxies may be responsible, just as massive planets can change the orbits of flimsy comets in our Solar System.

Dwarf irregular galaxies (shown as ringed dots on Figure 1) are less shy about advertising their presence. These formless little clumps of stars can even be seen in other clusters of galaxies, and seem to be extremely common in the Universe. The biggest contain about a hundred million stars, making them some hundred times larger than the dwarf elliptical galaxies; but by contrast, these are luminous white and blue stars, blazing with the fires of youth. The dwarf irregular galaxies are unmistakably young, vigorous systems, rich in gas poised to form into generations of stars. And although the majority are relatively large, one of them has the distinction of being the smallest galaxy yet discovered. Shaped like a cosmic footprint, tiny GR 8—only recently confirmed as a Local Group member—is only a thousand light-years across.

Before leaving the realms of the dwarf galaxies, let us briefly consider the question of their distribution within the Local Group. A glance at Figure 1 shows that the dwarfs—especially the elliptical dwarfs—cluster in swarms about the giant galaxies. Dwarf irregulars, on the other hand, tend to be fairly evenly spread. Why this should be is not yet understood; but theorists believe that it could be telling us much about the way galaxies form.

The uneven distribution has prompted some astronomers to suggest that a giant galaxy and its retinue of dwarf ellipticals constitute a total system called a 'Hypergalaxy'. This, in effect, is a colossal Solar System, the giant galaxy taking the place of the Sun, with the dwarf ellipticals bound by its gravity in orbits, like planets. A few astronomers have gone so far as to say that the Local Group, as we understand it, does not exist; but is an effect arising from the closeness of two independent hypergalaxies—the Andromeda galaxy and our own. But as long as this remains an open question, we can continue to believe in the idea of a Local Group. Much work has still to be

done on the motions of galaxies and the statistics of their distribution, before hypergalaxies become fact—if they ever do. There is, as yet, no compelling evidence that the dwarf galaxies around us are gravitationally bound to the Galaxy. They may well be making close approaches before winging off on orbits which will once again carry them into the depths of intergalactic space.

Even the Milky Way's closest companions—the Magellanic Clouds—may not be permanent satellites. These two irregular galaxies are only 160,000 light-years away, appearing as glowing patches in Southern Hemisphere skies. They are by no means dwarf galaxies; even the Small Magellanic Cloud (SMC) has one-sixth the diameter of our Milky Way, while the Large Magellanic Cloud (LMC) is over a quarter as large. Both contain thousands of millions of stars and resemble the Galaxy in their rich and varied mixture of objects. The LMC is particularly similar, and its prominent central 'bar' of stars has led to suggestions that it may be a very clumpy barred spiral galaxy—and not an irregular, after all.

The Magellanic Stream

Like all spiral and irregular galaxies, the Magellanic Clouds are rich in cold, invisible hydrogen gas—the raw material of future stars. Its characteristic signal at 21 centimetres wavelength allows radio astronomers to map its distribution; and they have long known both Clouds to be embedded in the same giant cocoon of gas, believed to have remained from the days of the Clouds' formation. But recent work with the radio telescope at Parkes, Australia, has led to spectacular new developments; the discovery of a huge intergalactic streamer of gas linking the Clouds to our Galaxy and stretching perhaps 200,000 light-years into remote space in the opposite direction. Astronomers have estimated that this 'Magellanic Stream' contains a mass of gas equivalent to a thousand million stars—as much as the Small Magellanic Cloud itself.

How did this colossal streamer arise? Some astronomers believe that an over-close approach by the SMC to our Galaxy some hundred million years ago caused vast amounts of gas to

be torn out of both systems. We see the evidence for such encounters throughout the Universe; distorted galaxies connected by ragged, broken filaments to each other. But the enormous tidal forces involved in this interaction would almost certainly have drastically separated the Clouds; and yet we see them still bound together in their 'foetal' gas. So the origin of the Stream is still a matter for speculation. Could it mark the orbital path of the Clouds, as some believe? Did it arise from collisions between the gas in the SMC and the unimaginably tenuous intergalactic medium? Many even more exotic theories will need to be tested before a consensus is reached.

Hot on the heels of the discovery of the Stream came reports from other radio observatories of more intergalactic gas clouds and streamers. Jodrell Bank astronomers detected a cloud only one degree away from the Andromeda galaxy; another was discovered close to the galaxy, M 33. Great cloud complexes were found outside the Local Group in several nearby clusters of galaxies; in particular, the Sculptor group has some ten clouds associated with its brightest members. If these clouds are genuinely near the galaxies they lie close to in the sky—and there is no direct way of measuring their distances—then it seems certain that clusters of galaxies have a small, but not insignificant amount of their matter in the form of cool gas clouds. Several astronomers now believe the Local Group, and other clusters, to be threaded with ribbons and streamers of gas.

But what do these clouds represent? Many are as big as 150,000 light-years across and contain a mass equivalent to hundreds of millions of stars. Might they be about to form into irregular galaxies? This is the tempting suggestion proffered by a few theorists; but other calculations indicate that the clouds are unstable, and will tend to expand, rather than contract to form stars. A great deal of work clearly remains to be done before their true nature becomes known; but it is gratifying that this new knowledge was triggered by discoveries made within our Local Group.

Is there anything left to discover?

We have, by now, surveyed the Local Group fairly thoroughly. Surely, nothing remains to be discovered, except perhaps an occasional dwarf galaxy, tramp globular cluster, or small gas cloud? But we have reckoned without one very important fact: there are parts of our Local Group which we cannot easily see. The dust in the disk of our Galaxy not only shrouds our view of the galactic centre; it also prevents us from seeing clearly into space in all directions along the galactic plane.

Although our eyes and optical telescopes cannot penetrate the fog, long infrared wavelengths can. An astronomer called Maffei made a special search of the galactic plane at these wavelengths in 1968, and was rewarded by the discovery of two highly obscured objects lying close to each other only half a degree from the plane. But they were amorphous, fuzzy patches which could just as easily have been globular clusters as galaxies. So followed an ambitious research programme—using the world's finest instruments—to establish their true identity.

Both objects—Maffei I and Maffei II—proved to be galaxies. More excitingly, Maffei I was shown to lie only three million light-years away—well within the Local Group. But most astonishing of all was the discovery that Maffei I is almost certainly a giant elliptical galaxy; the sort which populates the huge clusters of galaxies, and not little backwaters like our Local Group. Because of the tremendous obscuration in our own Galaxy—less than one-hundredth of Maffei I's light gets through to us—it is difficult to estimate just how big it is; but astronomers think it could well be as massive as the Galaxy, or even Andromeda.

If these findings are correct, it is a staggering discovery—perhaps the biggest galaxy in the Local Group, hidden from our sight by a thick band of dust in our own Galaxy. Yet Maffei I's claim to membership of the Local Group does raise a few problems. Its kinetic energy—due to its large measured velocity and its huge mass—is enormously greater than that of any other member, which raises severe doubts as to whether the

Local Group is stable. But rather than admit the Local Group is flying apart, astronomers prefer to believe that Maffei I is a stray galaxy just 'passing through'—and not a permanent resident.

What about Maffei II? It lies only three-quarters of a degree from Maffei I, and has a very similar velocity; yet it has been shown to be a spiral galaxy, well outside the Local Group at a distance of some 15 million light-years. This may put it among the members of the Ursa Major-Camelopardus cloud of galaxies. But some astronomers are uneasy; they feel that the coincidence of position and velocity between Maffei I and II shows that they must be somehow related. Maffei II is almost certainly at the greater distance; yet there are strong reasons for believing that Maffei I cannot be as far away as that. Which is the right answer? Are both—or neither—within the Local Group?

The same questions seemed destined to be asked again, following on from a very recent discovery by astronomers at Heidelberg, Germany. Searching a highly obscured region of the galactic plane, near the North America Nebula in Cygnus, they found two indistinct objects, one uncannily resembling Maffei I in both apparent size and light distribution. Another giant member of the Local Group? Was our little cluster greater in stature than we had hitherto believed? It was clearly important to find out.

Astronomers were quick off the mark to follow up the Heidelberg discoveries, and both objects have now been examined with the Hale 5-metre telescope. One is a spiral galaxy similar to our own; the other a bright elliptical. It seems from their apparent brightness that both lie well beyond the boundaries of the Local Group—perhaps as far as 30 million light-years away. But this is still close on an extragalactic scale, and their discovery will add much to our knowledge of nearby galaxies.

It is encouraging—even if slightly disquieting—that discoveries continue to be made on our doorstep, amidst familiar territory we believed we understood. So much obviously remains to be learned about normal galaxies, before we can

tackle the more exotic problems of extragalactic astrophysics with confidence. But we have a head start; if we probe diligently enough, our Local Group will provide some of the answers.

Interstellar and Intergalactic Matter

IAIN NICOLSON

Ten years ago I wrote an article for the 1968 *Yearbook* on the subject of 'Interstellar Dust', the tiny solid grains which are responsible for obscuring our view of the galactic centre. Although in the past decade there has not been a great change in our view of the nature of the grains, our knowledge of the interstellar and intergalactic medium in general has grown out of all recognition. Ten years ago we had no idea that a wide variety of complex molecules exist in gas clouds, and the notion that matter might exist in the space between the galaxies was regarded as being highly speculative—certainly, there was no good evidence to support such a suggestion. Today, the evidence for intergalactic material is strong and the debate is concerned with *how much* material exists in this form.

These dramatic advances in our knowledge owe much to developments in techniques and instrumentation, both in ground-based and space-borne astronomy. Advances in optical and radio astronomy, and the development of infrared astronomy have allowed Earth-based observers to gain a more comprehensive set of observations, while satellites—orbiting above the masking effects of the atmosphere—have provided vital observations, particularly in the X-ray and ultra-violet regions of the spectrum. Such short-wavelength radiation is prevented from reaching the Earth's surface (which is good for us, but a nuisance for the astronomer!) by absorption in the upper atmosphere, and X-ray astronomy in particular can only be carried out by means of rockets or satellites; the first rocket experiment was carried out in 1962, and the first satellite devoted to X-ray astronomy (the U.S. Explorer satellite

UHURU) was launched in 1970. High altitude balloons, too, have made a contribution by carrying instrumentation sensitive to long-wave infra-red and short-wave microwave radiation.

In what follows I hope to be able to give an overall impression of our present knowledge of interstellar and intergalactic matter and to highlight some of the problems and uncertainties.

Interstellar Matter

Matter between the stars exists in two basic forms, *gas* (ions, atoms, and molecules) and *dust* (small solid particles, or *grains*) and the generally accepted view is that the gas makes up about 10 per cent of the mass of our Galaxy while the dust comprises only 1 per cent of the interstellar material, i.e. 0.1 per cent of the galactic mass.

The most obvious evidence for the gas is the existence of luminous nebulæ, such as the well-known Orion Nebula (M42), which are gas clouds shining by absorbing ultra-violet radiation from hot stars embedded within them, a re-emitting visible light. These luminous *emission nebulæ* are also known as *HII regions* because they are largely composed of ionized hydrogen. Evidence for gas spread more generally through the galaxy comes from *interstellar lines*, dark lines superimposed on the spectra of stars due to absorption of starlight at particular wavelengths as that light passes through the interstellar gas *en route* from the stars to the Earth. Further vital evidence comes from the 21-cm radiation emitted by neutral (un-ionized) hydrogen. That hydrogen would emit radiation of that wavelength (corresponding to a frequency of 1,420 MHz) was predicted by H. C. van de Hulst in 1945 and this radiation was first detected by radio astronomers in 1951. Because such radiation is not affected by interstellar dust (unlike visible light, which is absorbed) it has proved possible to study the distribution of neutral hydrogen (HI regions) through virtually the entire extent of our Galaxy, and in this way the spiral structure of the system has been dramatically revealed.

The presence of the dust is revealed in a number of ways.

Dark nebulæ, such as the famous 'Horse-Head' nebula in Orion or the 'Coal Sack' in the southern Milky Way, testify to the obscuring effect of relatively dense dust clouds. Such clouds consist of a mixture of gas and dust, but whereas the gas does not appreciably attenuate starlight, the dust obscures the light from stars lying beyond. *Reflection nebulæ* provide further evidence for dust; for example, long exposure photographs of the brighter stars in the Pleiades cluster show them to be surrounded by faint nebulosity due to the reflection of light from dust particles in the vicinity of these stars. The spectrum of light from a reflection nebula is almost exactly the same as that from the central star (the starlight being reflected by the dust) and quite unlike the bright emission line spectrum characteristic of HII regions; HII regions are made to shine only by the hottest and most luminous types of star (stars of spectral type O).

Evidence for dust spread throughout the plane of our Galaxy comes from the phenomena of interstellar *reddening* and *extinction*, and from interstellar *polarization*, and it is from observations of these phenomena that our understanding of interstellar grains has come. By comparing distant stars with nearby stars of the same type we find that stars near the plane of our Galaxy appear both fainter and more red in colour than we would expect. Light from distant stars is scattered by the intervening dust particles with the result that a certain proportion is absorbed in space, the amount of extinction—on average—amounting to one stellar magnitude per kiloparsec; this means that a star at a distance of one kiloparsec (3,260 light years) will appear to be only about two-fifths of the brightness we would expect it to have at such a distance. The amount of extinction which occurs depends on the wavelength of light, and over the optical region of the spectrum, the extinction is more or less inversely proportional to wavelength, i.e. the amount of extinction *increases* with *decreasing* wavelength. As a result, blue light is more strongly absorbed than red light, and the proportion of red light compared to blue light which we *receive* from a star is greater than the proportion of red to blue light *emitted* by the star; in other words, the star appears

redder than it ought to do. This is the phenomenon of interstellar reddening.

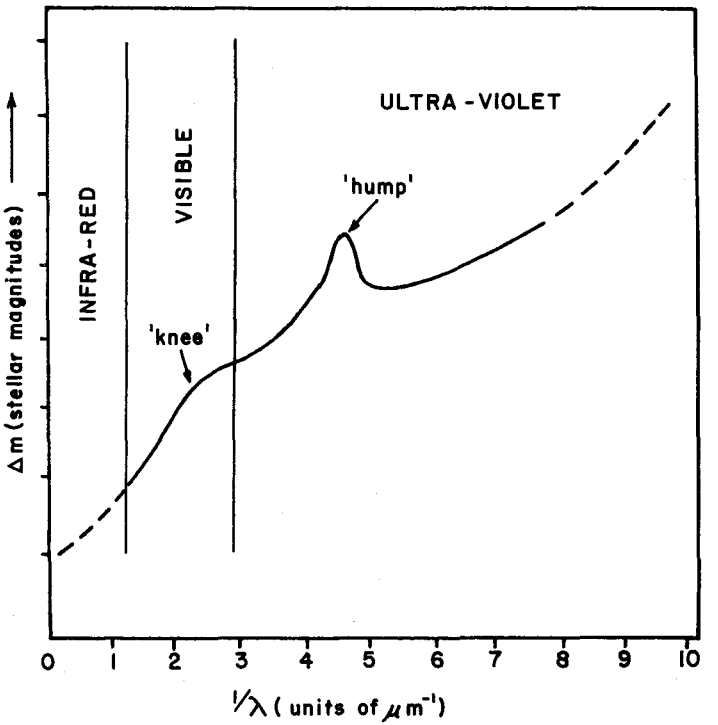

Figure 1. Interstellar extinction: The amount of extinction (Δm), expressed in stellar magnitudes is plotted against $1/\lambda$ where λ is the wavelength of radiation expressed in terms of the number of waves per micrometre (thus the figure 2 on the horizontal scale corresponds to two waves per micrometre (μm), i.e. a wavelength of 0.5 micrometres)

In recent years, observations of interstellar extinction have been made in the infra-red and ultra-violet parts of the spectrum as well as the optical region and the resulting *extinction curve* is illustrated in Figure 1, where the amount of light absorbed (Δm, measured in magnitudes) is plotted against $1/\lambda$, where λ denotes the wavelength of radiation. In

the near infra-red the amount of extinction is small and varied considerably from place to place in the Galaxy. At optical wavelengths, the amount of extinction is inversely proportional to wavelength, but a curious feature is the pronounced change in slope which occurs at a wavelength of about 430 nanometres (4,300 Ångströms, in old-fashioned units). The amount of extinction increases at ultra-violet wavelengths and, although there are differences in different parts of the Galaxy, the most striking feature is the 'hump' at $1/\lambda = 4.6$ (i.e. a wavelength of 220 nanometres).

The general features of the extinction curve suggest that the particles responsible must be small, ranging in radius from 10^{-8} to 10^{-6} metres (i.e. from a hundred millionth to a millionth of a metre) so that the average grain is smaller than the wavelength of visible light. The infra-red observations are complicated in some cases by that fact that there are stars which have circumstellar dust shells—these shells absorb radiation from the central stars, re-emitting it in the infra-red part of the spectrum (the infra-red properties of dust clouds and circumstellar shells have been covered in previous *Yearbook* articles, e.g. by D. A. Allen, 'The Dusty Sky', and M. Cohen, 'Ice in Space', both in the 1977 edition). Many models of grains have been proposed to try to account for the extinction curve, but as yet no single model has proved to be satisfactory. The most popular models suggest that the grains may be composed of silicates, or graphite (a form of carbon), but other possibilities include iron and ice, and core-mantle grains (a graphite core, coated with, for example, water ice). Graphite grains could account for the ultra-violet 'hump' since graphite absorbs strongly at about this wavelength, but it would seem that very small particles would be required. Silicate grains could account for strong absorption observed at certain infra-red wavelengths in the spectra of highly reddened stars. Ice also produces absorption at infra-red wavelengths, and in the past few years such features have been observed.

The situation is rather confused and the best hope at present is that some mixture of grains of differing composition and sizes will fit the observations.

Measurements of polarization* reveal that the grains are not spherical, but elongated. If the long axes of the grains can be aligned in some way—for example by the galactic magnetic field—then they will preferentially absorb light vibrating in one particular plane, so giving rise to polarized starlight. Thus, it seems in the light of present evidence, that interstellar dust is made up of elongated grains, possibly of graphite, ice or silicates, comparable with or smaller than the wavelength of visible light.

The origin of the grains remains something of a problem. It is generally agreed that formation of graphite grains may take place in the atmospheres of cool carbon-rich stars, and that after their formation, the grains are driven out from these stars by the pressure of radiation. Thus, we can visualize carbon stars leaving a trail of 'smoke' in their wake! A similar process could lead to the formation of silicate grains in oxygen-rich stars. A basic problem is that current estimates suggest that only a tenth of the supposed quantity of grains could be produced in this way. It may be that grain formation takes place in circumstellar shells, too, or that larger grains grow in interstellar space on the smaller grains expelled from stars. For the moment, however, it is not at all clear where all the grains have come from. And there is a 'chicken and egg' problem too—some theories suggest that grains may be necessary to assist the process of star formation, but if the grains have to be formed in stars in the first place...?

The possibility that there may be far less dust in space than we have hitherto supposed has also been raised. The conventional view is that the mean density of interstellar *gas* is about 10^{-21} kg per cubic metre (about one thousand million million millionth of the density of air at ground level!) and that of the

**Polarization:* A light wave vibrates in a plane perpendicular to its direction of motion. An unpolarized beam of light contains waves vibrating in every plane while a plane polarized beam contains waves vibrating in one plane only. Light may be in any state of polarization between these two extremes, and analysis of polarization can tell us a great deal about the origin of the light, or what has happened to it between leaving its source and reaching the Earth.

dust about 10^{-23} kg per cubic metre. Satellite observations appear to indicate that some of the heavy elements (such as silicon) expected to be contained in grains are in shorter supply in interstellar space than was previously thought. Furthermore, Wesson and Lerman have argued that spinning dust grains ought to emit microwave radiation, and the fact that this radiation has not yet been detected implies that the mean space density of dust grains may be less than one-thousandth of the conventional value. If these arguments are confirmed then it may be that our view of the quantity and/or composition of interstellar grains will have to be revised.

Whatever the mean density of dust may be, the dark dense gas and the dust clouds which we know to exist provide the ideal setting for the formation of complex molecules. Until comparatively recently it had been thought that conditions in space were wholly inimical to the formation of molecules, but in 1963 came the discovery of one of the simplest, hydroxyl (OH), a combination of oxygen and hydrogen. In the past decade, the number of molecular species detected has exceeded three dozen; although some of the simpler species such as OH and H_2 (molecular hydrogen) reveal themselves by their absorption of visible or ultra-violet light, all other molecules have been detected by their absorption or emission of radiation at microwave and radio wavelengths.

Molecules rotate and vibrate; changes in the rotational states accompany absorption and emission at microwave frequencies, while infra-red molecular spectra result from changes in the vibrational states. Some of the molecular species emit radiation by acting as masers. The molecules which have been found are predominantly *organic*, and examples include formaldehyde (H_2CO), formic acid (HCOOH), and ethyl alcohol (C_2H_5OH). A particularly interesting cloud, rich in molecules (and containing practically all the types of molecule so far discovered) is Sagittarius B2 (SgrB2), a massive cloud, containing several million solar masses of material, lying close to the galactic centre. Within this cloud alone it has been estimated that there is sufficient ethyl alcohol to make up 10^{28} measures of proof spirit—more than enough to fill the entire

Earth with alcohol! What an incentive to develop interstellar travel!

Intergalactic matter

Clearly the interstellar medium is a fascinating laboratory offering tremendous scope for observational and theoretical work, and many problems remain to be solved. What do we know of the space between the galaxies?

We can certainly rule out the possibility that there exists large quantities of intergalactic dust similar to interstellar grains. Intergalactic space is very transparent; we can see galaxies at ranges of over 10^{10} (ten thousand million) light years and this implies that the mean density of dust must be less than a few times 10^{-30} kg per cubic metre. If we were to assume that the proportion of gas to dust in intergalactic space were the same as that found in the Galaxy then we would expect to find less than a few times 10^{-28} kg per cubic metre of gas between the galaxies. However, since we believe that the heavy dust particles are produced in the more recent generations of stars in galaxies, and that the Universe originated a finite time ago, it is likely that the proportion of dust in intergalactic space will be very much less than that found in the Galaxy. A lack of intergalactic *dust*, therefore, does not necessarily imply that there must be very little intergalactic *gas*.

The *amount* of intergalactic matter (gas, dust, or whatever) is of profound cosmological importance. The evidence at present favours the 'Big-Bang' origin of the Universe, i.e. that the Universe 'began' in a hot explosive event nearly twenty thousand million years ago. At present the Universe is expanding but, due to the mutual gravitational attraction of matter, the expansion is slowing down. Either the expansion will slow down to a steady level and continue without limit, or, if the mean density of matter in the Universe exceeds a certain value (the *critical density*), the expansion will eventually halt, to be followed by a contraction phase. Estimates of the mean density based on the observed number of galaxies fall far below the critical density (which is about 5×10^{-27} kg per cubic metre), by a factor of between ten and a hundred, but if large amounts of

intergalactic and invisible matter exist, then there may be sufficient mass eventually to halt the expansion.

Evidence for intergalactic matter has built up in the past decade from widely different types of observations. Firstly, there is the question of the 'missing mass' in clusters of galaxies. The galaxies which make up a cluster all have their individual motions and so possess kinetic energy; in order that the members be held together the cluster must contain sufficient mass such that the gravitational attraction exerted on each galaxy prevents its escaping from the group. There is a theorem, known as the *virial theorem*, which relates the kinetic energy of galaxies in a cluster to the gravitational potential energy of the cluster, and by observing the distribution and motions of galaxies within a cluster it is possible to deduce the expected mass of the cluster. In many cases the mass deduced from counting the number of galaxies is far less than the *virial mass* of a cluster and it follows that there must be a large amount of unseen 'missing' matter in such clusters. An example is the Coma cluster, some 450 million light years distant, which contains about a thousand galaxies, the combined mass of which has been estimated at 6×10^{14} solar masses. However, the virial theorem tells us the mass of the cluster should be about ten times greater than this. Where is the missing mass? Is it contained in very faint galaxies which cannot be seen, in the outer parts of galaxies which do not show up in photographs, in massive black holes, or is it contained in intergalactic gas within the cluster?

Radio astronomy provides another clue. A typical radio galaxy consists of two radio-emitting regions (probably clouds of electrons) stretching out on either side of a central optical galaxy. In some cases, the shape of the radio sources (which appear to have 'tails') suggests that the radio-emitting material is moving through a resisting medium of intergalactic gas. For example, the radio tails observed in the Perseus cluster could be explained by the existence of intergalactic gas within the cluster having a density a thousand times greater than the critical density.

The most striking recent evidence has come from X-ray

observations. No less than twenty of the X-ray sources catalogued by the UHURU satellite turned out to be clusters of galaxies. Of the possible mechanisms for producing X-rays, the most reasonable at present is to assume that the radiation comes from a hot intergalactic gas (with temperatures of a few hundred million degrees Kelvin) in these clusters. Quite good agreement between observation and theory has been obtained in the cases of the Perseus and Coma clusters. For example, the Coma X-ray results could be explained by a hot gas having a total mass about 5×10^{14} solar masses, i.e. about the same amount of mass exists in the form of hot gas as is tied up in the galaxies in this particular cluster. Even if this is so, however, the combined mass of galaxies and gas is still less than a quarter of the virial mass—the problem of missing mass in the Coma cluster remains.

Recent observations by Gull and Northover of Cambridge appear to provide further support for the existence of hot gas in clusters. The cosmic microwave radiation (which appears to be radiation filling space and dating from the 'Big Bang') should interact with electrons in the hot gas within clusters to produce a small diminution of the observed 'temperature' of this radiation compared to the general background. Their observations of a number of clusters (including the Coma cluster), although tentative, do appear to show the effect.

Taking all the evidence into account, it does begin to look as if, within clusters, there may be a tenuous gas (a few hundred atoms per cubic metre) at a temperature of a few hundred million degrees absolute. It is as yet uncertain where this gas came from; possibly it may have been expelled from the member galaxies in the past, or it may have fallen into the clusters from inter-cluster space. Whatever its origin, it looks at present as if intergalactic gas cannot—of itself—wholly account for the 'missing mass' in clusters.

Evidence for gas between clusters is much more tenuous. Attempts to detect inter-cluster neutral hydrogen or low-temperature ionized gas have not met with success, but it is still possible that a hot rarefied gas may exist. G. B. Field has suggested that the diffuse background X-ray radiation which

has been observed could be acounted for by a hot gas in intercluster space, having a temperature of hundreds of millions of degrees Kelvin, but a density appreciably less than one-tenth of the critical density. At present, though, it is too early to make definite pronouncements about gas between clusters of galaxies.

There is a cosmological argument which argues against very large amounts of intergalactic matter. It is assumed (accepting the 'Big Bang' model) that most of the helium in the Universe was formed at the high temperature which prevailed in the first few minutes after the 'Big Bang'. Likewise, the observed cosmic abundance of the element deuterium ('heavy' hydrogen) can best be explained by assuming it was formed in the 'Big Bang'. The amount of deuterium formed depends strongly on the initial temperature and density of the Universe and to account for the observed quantities of deuterium we require that the mean density of matter in the Universe be no more than 10 or 20 per cent of the critical density. It is possible that the mean density of matter is greater than this, but if so, some other explanation of the origin of deuterium will be required.

Taking all the strands of evidence together, it appears pretty certain that intergalactic matter exists, but that its mean density is probably less than one-tenth of the critical density. There does not seem to be sufficient matter to 'close' the Universe and it looks as if the expansion must continue for ever. However, there is still sufficient uncertainty to make us very wary of making such a dogmatic statement, and it may be that the intergalactic medium has many surprises in store for us in the years ahead.

Summary

Interstellar space in our Galaxy is filled with a tenuous mixture of gas (predominantly hydrogen and helium), and dust, the mean overall density of which is about 10^{-21} kg per cubic metre. The dust is thought to comprise about 1 per cent by mass of the interstellar matter, but there is some evidence to suggest its contribution may be much less. Intergalactic matter appears to exist in clusters of galaxies in the form of hot gas

having a mean density of 10^{-24} kg per cubic metre in the case of clusters which are X-ray sources. Hot gas *may* exist between clusters of galaxies but the evidence as yet is rather uncertain, and there does not seem to be nearly enough matter to halt the headlong expansion of the Universe. Our picture of space has changed dramatically from the vision of stark emptiness of the last century to the concept of a Universe filled with a tenuous but complex mixture of matter and radiation, and the study of the interstellar and intergalactic medium has been shown to have profound implications for most aspects of astronomy, from the formation of stars and planets to the origin and evolution of the Universe itself.

Recent Advances in Astronomy

PATRICK MOORE

It is seldom nowadays that a year passes without several spectacular new developments in astronomy and space research, but the months which have elapsed since I wrote my last 'Recent Advances' article, in the 1977 *Yearbook,* have been more fruitful than most. I must again stress that I am writing at the end of June, 1977. Who knows what else may have happened before my article appears in print.

Let us begin with the Solar System—and, frankly, something of an anti-climax. I think everyone had hoped that the Viking missions would give a final answer to the age-old question: "Is there life on Mars?" Regrettably, they have not. No definite signs of life have been detected; it is too early to say that Mars is sterile, but the Viking search for life is over, and the biology instruments in both Landers were switched off at the end of May 1977. Moreover, Viking 2 has been 'closed down' to prepare for the Martian winter; Utopia is a cold place—colder than Chryse, the site of Lander 1, since it is closer to the pole. Most of the other experiments are still in working order, and both Landers may well have a reasonable 'active time' ahead of them—apart from the biology.

Pioneer II continues its journey toward a rendezvous with Saturn, and two more deep-space probes, Voyagers 1 and 2, are due to be launched in the late summer. (Both should be en route for Jupiter, the first rendezvous, before this *Yearbook* appears in print, though one must never be over-confident; remember Mariners 1 and 3!). But the main discovery of 1977 with regard to the outer planets has concerned Uranus, which has yielded up a long-kept secret.

On 10 March 1977 Uranus occulted a 9th-magnitude star, SAO 158687. Predictions were made by Gordon Taylor, of the Royal Greenwich Observatory, who has specialized in this kind of work, his main aim being to improve our knowledge of the diameters of objects which are difficult to measure directly.* Observations were made from the Kuiper Airborne Observatory, with its 36-inch reflector, and from South Africa. The results were totally unexpected. Before occultation, and again afterwards, the star 'winked' five times, and there can be only one explanation: Uranus is surrounded by a system of five rings which are so dim that they remain undetected (and are probably undetectable visually) from Earth. From the current data, it seems that the rings are contained in a narrow belt about 4,400 miles wide, lying 11,000 miles above the cloud-tops of Uranus itself. The first four are thought to be about 6 miles across, and to be almost circular. The outermost ring may be thicker—perhaps up to 60 miles—and may not be exactly circular.

Another discovery, made independently, is that both Uranus and Neptune are slower spinners than has been thought. The axial rotation period of Uranus is now thought to be between 17 and 22 hours; for Neptune, about 23 hours. Clearly there is much that we do not know about these remote giants, and astronomers eagerly await the moment in the year 1986 when it is hoped that Voyager 1 will by-pass Uranus and send us back information from close range.

Still in the Solar System: much has been heard of the comparative lack of activity in the Sun during recent years. The last maximum took place in 1969, so that the next should be due in 1980; but sunspots were rare in 1976 and the first half of 1977, and there were even suggestions that we were about to experience another 'Maunder Minimum' (the period between 1645 and 1715, when there were practically no spots at all and even the corona may have been absent, so that the solar cycle

*I am delighted to say that the 1979 *Yearbook* will contain two articles about Uranus—one by Gordon Taylor, whose predictions led directly to the discovery of the rings, and one by Dr. Garry Hunt, dealing with the make-up of this peculiar world.

was temporarily suspended). However, this appears most improbable, and it is overwhelmingly likely that activity will pick up rapidly from now on, though it is still not certain how energetic the next maximum will be.

Turning to the universe as a whole, there has been a fascinating discovery of a flat, disk-shaped, highly luminous stellar object: MWC 349, in Cygnus, which is a star surrounded by a disk of intensely glowing gas which may indicate that a planetary system is in the process of formation. The star itself is 10 times the size and 30 times the mass of the Sun; it is 10,000 light-years away, and is thought to be no more than a thousand years old. The total brightness of the object (star plus disk) is declining at about one per cent per month as luminous material from the disk spirals into the central star, so that the disk itself will cease to shine by AD 2077. The discovery was made by a team of astrophysicists headed by Dr. R. Thompson of the Steward Observatory, University of Arizona. It was announced only in June 1977, so that the data are far from complete as yet, but MWC 349 is evidently an object of tremendous significance.

Next comes the second visual identification of a pulsar. Pulsars—neutron stars—are detected by means of their rapidly-varying radio waves, but before 1977 the only pulsar which had been identified with a flashing object was that in the Crab Nebula. (It is amazing how often the Crab crops up in modern astronomy!) It was, however, thought that there might be a possibility of tracking down light from another pulsar, PSR 0833–45 in the southern constellation of Vela, which had been discovered in 1968 at the Molongo Radio Astronomy Observatory in Australia. The Vela pulsar has a period of 0.089 second, the third shortest known (the shortest of all is the Crab pulsar, with 0.033 second), indicating that it is young, with an age of less than 10,000 years. Fairly obviously it is a supernova remnant, and it is associated with an extended area of optical nebulosity and radio emission.

At Siding Spring, in Australia, a team of researchers including Professor Graham Smith, Director of the Royal Greenwich Observatory, and Dr. Paul Murdin, also from Greenwich,

carried out a careful search—and were successful. The Vela pulsar was identified with an excessively faint object which had been discovered in 1975 by B.M. Lasker at the Cerro Tololo Observatory in Chile. The visual magnitude is of approximate magnitude 25, which means that it is the faintest object ever recorded—yet another record. It is much dimmer than the Crab pulsar, which has a visual magnitude of 17. The Siding Spring triumph gives hope that in the foreseeable future other pulsars may be optically identified, though the task is an extremely difficult one. It is, incidentally, notable that we now know more about pulsars than we do about quasars, which were discovered considerably earlier but which remain very enigmatical indeed.

New telescopes continue to be built (one of the latest is an 84-inch in Argentina, several hundred miles west of Buenos Aires), though the Russian 236-inch remains supreme in point of size; whether it will ever be surpassed by an Earth-based instrument remains to be seen. So far as England is concerned, the largest telescope has been the 98-inch at Herstmonceux; it is far greater in aperture than any other British telescope—indeed, its nearest rival has been the remarkable 72-inch built by the third Earl of Rosse as long ago as 1845, but which has now been out of use for more than sixty years. Unfortunately, it has to be admitted that the English climate is not ideal astronomically, and the 98-inch cannot often be used to its full capacity. For some time there have been plans to transfer it to a better site, and it has now been decided that the new Northern Hemisphere Observatory (NHO for short) will be set up at La Palma, in the Canary Islands. The 98-inch telescope is to be transferred there, equipped with a new mirror which will actually be a full 100 inches across and, of course, with a highly modified mount to allow for the difference in latitude. In a way it is a pity that Herstmonceux should lose its largest telescope, but clearly the decision has been in the best interests of science. It is worth adding, incidentally, that a major public exhibition has now been opened at Herstmonceux, and is proving extremely popular with the many visitors who go there.

On the debit side, we have lost one of our greatest astronom-

ers: Dr. Donald H. Menzel, who was eminent in so many fields and was particularly renowned for his work in connection with the Sun. Dr. Menzel's death was sudden and unexpected; he will be sadly missed, not only for his scientific eminence but also for his outstanding personal qualities. I knew him well, and so can speak with authority.

What lies ahead? Progress is now amazingly rapid in both space research and what may be termed 'old-fashioned astronomy'. Photography itself is giving way to electronic methods; in America, the Space Shuttle is being prepared; artificial satellites are providing striking new information about topics such as X-ray astronomy, and it must be added that a large new English infra-red telescope is being erected in Hawaii. Astronomy now is very different from that of 1962, when the first *Yearbook* was published. Exciting times lie ahead.

PART THREE

Miscellaneous

Some Interesting Telescopic Variable Stars

Star	R.A. *h*	*m*	Dec. °		*Mag. range*	*Period, days*	*Remarks*
R. Andromedæ	0	22	+38	18	6.1–14.9	409	
W Andromedæ	2	14	+44	4	6.7–14.5	397	
Theta Apodis	14	00	−76	33	6.4– 8.6	119	Semi-regular.
R Aquilæ	19	4	+ 8	9	5.7–12.0	300	
R Arietis	2	13	+24	50	7.5–13.7	189	
R Aræ	16	35	−56	54	5.9–6.9	4	Algol type.
R Aurigæ	5	13	+53	32	6.7–13.7	459	
R Boötis	14	35	+26	57	6.7–12.8	223	
Eta Carinae	10	43	−59	25	−0.8– 7.9	—	Unique erratic variable.
I Carinæ	09	43	−62	34	3.9–10.0	381	
R Cassiopeiæ	23	56	+51	6	5.5–13.0	431	
T Cassiopeiæ	0	20	+55	31	7.3–12.4	445	
X Centauri	11	46	−41	28	7.0–13.9	315	
T Centauri	13	38	−33	21	5.5– 9.0	91	Semi-regular.
T Cephei	21	9	+68	17	5.4–11.0	390	
R Crucis	12	20	−61	21	6.9– 8.0	5	Cepheid.
Omicron Ceti	2	17	− 3	12	2.0–10.1	331	Mira.
R Coronæ Borealis	15	46	+28	18	5.8–14.8	–	Irregular
W Coronæ Borealis	16	16	+37	55	7.8–14.3	238	
R Cygni	19	35	+50	5	6.5–14.2	426	
U Cygni	20	18	+47	44	6.7–11.4	465	
W Cygni	21	34	+45	9	5.0– 7.6	131	
SS Cygni	21	41	+43	21	8.2–12.1	–	Irregular.
Chi Cygni	19	49	+32	47	3.3–14.2	407	Near Eta.
Beta Doradûs	05	33	−62	31	4.5– 5.7	9	Cepheid.
R Draconis	16	32	+66	52	6.9–13.0	246	
R Geminorum	7	4	+22	47	6.0–14.0	370	
U Geminorum	7	52	+22	8	8.8–14.4	–	Irregular.
R Gruis	21	45	−47	09	7.4–14.9	333	
S Gruis	22	23	−48	41	6.0–15.0	410	
S Herculis	16	50	+15	2	7.0–13.8	307	
U Herculis	16	23	+19	0	7.0–13.4	406	
R Hydræ	13	27	−23	1	4.0–10.0	386	
R Leonis	9	45	+11	40	5.4–10.5	313	Near 18, 19.
X Leonis	9	48	+12	7	12.0–15.1	–	Irregular (U Gem type).
R Leporis	4	57	−14	53	5.9–10.5	432	'Crimson star.'
R Lyncis	6	57	+55	24	7.2–14.0	379	
W Lyræ	18	13	+36	39	7.9–13.0	196	
T Normæ	15	40	−54	50	6.2–13.4	293	
HR Delphini	20	40	+18	58	3.6– ?	–	Nova, 1967.
S Octantis	17	46	−85	48	7.4–14.0	259	
U Orionis	5	53	+20	10	5.3–12.6	372	
Kappa Pavonis	18	51	−67	18	4.0– 5.5	9	Cepheid.
R Pegasi	23	4	+10	16	7.1–13.8	378	
S Persei	2	19	+58	22	7.9–11.1	810	Semi-regular.
R Sculptoris	01	24	−32	48	5.8– 7.7	363	Semi-regular.

Star	R.A. *h*	*m*	Dec. °	′	*Mag. range*	*Period days*	*Remarks*
R Phoenicis	23	53	−50	05	7.5–14.4	268	
Zeta Phœnicis	01	06	−55	31	3.6– 4.1	1	Algol type.
R Pictoris	04	44	−49	20	6.7–10.0	171	Semi-regular.
L^2 Puppis	07	12	−44	33	2.6– 6.0	141	Semi-regular.
Z Puppis	07	30	−20	33	7.2–14.6	510	
T Pyxidis	09	02	−32	11	7.0–14.0	–	Recurrent nova (1920, 1944)
R Scuti	18	45	− 5	46	5.0– 8.4	144	
R Serpentis	15	48	+15	17	5.7–14.4	357	
SU Tauri	5	46	+19	3	9.2–16.0	–	Irregular (R CrB type).
R Ursæ Majoris	10	41	+69	2	6.7–13.4	302	
S Ursæ Majoris	12	42	+61	22	7.4–12.3	226	
T Ursæ Majoris	12	34	+59	46	6.6–13.4	257	
S Virginis	13	30	-6	56	6.3–13.2	380	
R Vulpeculæ	21	2	+23	38	8.1–12.6	137	

Note: Unless otherwise stated, all these variables are of the Mira type.

Some Interesting Double Stars

The pairs listed below are well-known objects, and all the primaries are easily visible with the naked eye, so that right ascensions and declinations are not given. Most can be seen with a 3-inch refractor, and all with a 4-inch under good conditions, while quite a number can be separated with smaller telescopes, and a few (such as Alpha Capricorni) with the naked eye. Yet other pairs, such as Mizar-Alcor in Ursa Major and Theta Tauri in the Hyades, are regarded as too wide to be regarded as bona-fide doubles!

Name	*Magnitudes*	*Separation″*	*Position angle, deg.*	*Remarks*
Gamma Andromedæ	3.0, 5.0	9.8	060	Yellow, blue. B is again double (0″.4) but needs a larger telescope.
Zeta Aquarii	4.4, 4.6	2.6	291	Becoming more difficult.
Gamma Arietis	4.2, 4.4	8	000	Very easy.
Theta Aurigæ	2.7, 7.2	3	330	Stiff test for 3 in. OG
Delta Boötis	3.2, 7.4	105	079	Fixed.
Epsilon Boötis	3.0, 6.3	2.8	340	Yellow, blue. Fine pair.
Kappa Boötis	5.1, 7.2	13	237	Easy.
Zeta Cancri	5.6, 6.1	5.6	082	
Iota Cancri	4.4, 6.5	31	307	Easy. Yellow, blue.
Alpha Canum Venat.	3.2, 5.7	20	228	Yellowish, bluish. Easy.
Alpha Capricorni	3.3, 4.2	376	291	Naked-eye pair. Alpha again double.
Eta Cassiopeiæ	3.7, 7.4	11	298	Creamy, bluish. Easy.
Beta Cephei	3.3, 8.0	14	250	
Delta Cephei	var, 7.5	41	192	Very easy.

Name	*Magnitudes*	*Separation"*	*Position angle, deg.*	*Remarks*
Alpha Centauri	0.0, 1.7			Binary; period 80 years. Very easy.
Xi Cephei	4.7, 6.5	6	270	Reasonably easy.
Gamma Ceti	3.7, 6.2	3	300	Not too easy.
Alpha Circini	3.4, 8.8	15.8	235	PA, slowly decreasing.
Zeta Coronæ Borealis	4.0, 4.9	6.3	304	
Delta Corvi	3.0, 8.5	24	212	
Alpha Crucis	1.6, 2.1	4.7	114	Third star in low-power field.
Gamma Crucis	1.6, 6.7	111	212	Wide optical pair.
Beta Cygni	3.0, 5.3	35	055	Yellow, green. Glorious.
61 Cygni	5.3, 5.9	25	150	
Gamma Delphini	4.0, 5.0	10	265	Yellow, greenish. Easy.
Nu Draconis	4.6, 4.6	62	312	Naked-eye pair.
Alpha Geminorum	2.0, 2.8	2	151	Castor. Becoming easier.
Delta Geminorum	3.2, 8.2	6.5	120	
Alpha Herculis	var, 6.1	4.5	110	Red, green.
Delta Herculis	3.0, 7.5	11	208	Optical double.
Zeta Herculis	3.0, 6.5	1.4	300	Fine, rapid binary.
Gamma Leonis	2.6, 3.8	4.3	121	Binary; period 400 years
Alpha Lyræ	0.0, 10.5	60	180	Vega. Optical; B faint.
Epsilon Lyræ	4.6, 6.3	3	005	Quadruple. Both pairs
	4.9, 5.2	2.3	111	separable in 3 in. OG
Zeta Lyræ	4.2, 5.5	44	150	Fixed. Easy double.
Beta Orionis	0.1, 6.7	9.5	205	Rigel. Can be split with 3 in.
Iota Orionis	3.2, 7.3	11	140	
Theta Orionis	6.0, 7.0			The famous Trapezium in
	7.5, 8.0			M.42
Sigma Orionis	4.0, 7.0	11.1	236	Quadruple. D is rather
		12.9	085	faint in small apertures.
Zeta Orionis	1.9, 5.0	3	160	
Eta Persei	4.0, 8.5	28.5	300	Yellow, bluish.
Beta Phoenicis	4.1, 4.1	1.3	352	Slow binary.
Beta Piscis Austrini	4.4, 7.9	30.4	172	Optical pair. Fixed.
Alpha Piscium	4.3, 5.3	1.9	291	
Kappa Puppis	4.5, 4.6	9.8	318	Again double.
Alpha Scorpii	0.9, 6.8	3	275	Antares, Red. green.
Nu Scorpii	4.2, 6.5	42	336	
Theta Serpentis	4.1, 4.1	23	103	Very easy.
Alpha Tauri	0.8, 11.2	130	032	Aldebaran. Wide, but B is very faint in small telescopes.
Beta Tucanæ	4.5, 4.5	27.1	170	Both components again double.
Zeta Ursæ Majoris	2.3, 4.2	14.5	150	Mizar. Very easy. Naked eye pair with Alcor.
Alpha Ursæ Minoris	2.0, 9.0	18.3	217	Polaris. Can be seen with 3 in.
Gamma Virginis	3.6, 3.7	4.8	305	Binary; period 180 yrs. Closing.
Theta Virginis	4.0, 9.0	7	340	Not too easy.
Gamma Volantis	3.9, 5.8	13.8	299	Very slow binary.

Some Interesting Nebulae and Clusters

Object	R.A.		Dec.		*Remarks*
	h	*m*	°		
M.31 Andromedæ	00	40.7	+41	05	Great Galaxy, visible to naked eye.
H.VIII 78 Cassiopeiæ	00	41.3	+61	36	Fine cluster, between Gamma and Kappa Cassiopeiæ.
M.33 Trianguli	01	31.8	+30	28	Spiral. Difficult with small apertures.
H.VI 33–4 Persei	02	18.3	+56	59	Double cluster; Sword-handle.
△142 Doradûs	05	39.1	−69	09	Looped nebula round 30 Doradûs. Naked-eye. In Large Cloud of Magellan.
M.1 Tauri	05	32.3	+22	00	Crab Nebula, near Zeta Tauri.
M.42 Orionis	05	33.4	−05	24	Great Nebula. Contains the famous Trapezium, Theta Orionis.
M.35 Geminorum	06	06.5	+24	21	Open cluster near Eta Geminorum.
H.VII 2 Monocerotis	06	30.7	+04	53	Open cluster, just visible to naked eye.
M.41 Canis Majoris	06	45.5	−20	42	Open cluster, just visible to naked eye.
M.47 Puppis	07	34.3	−14	22	Mag. 5,2. Loose cluster.
H.IV 64 Puppis	07	39.6	−18	05	Bright planetary in rich neighbourhood.
M.46 Puppis	07	39.5	−14	42	Open cluster.
M.44 Cancri	08	38	+20	07	Præsepe. Open cluster near Delta Cancri. Visible to naked eye.
M.97 Ursæ Majoris	11	12.6	+55	13	Owl Nebula, diameter 3′. Planetary.
Kappa Crucis	12	50.7	−60	05	"Jewel Box"; open cluster, with stars of contrasting colours.
M.3 Can. Ven.	13	40.6	+28	34	Bright globular.
Omega Centauri	13	23.7	−47	03	Finest of all globulars. Easy with naked eye.
M.80 Scorpii	16	14.9	−22	53	Globular, between Antares and Beta Scorpionis.
M.4 Scorpii	16	21.5	−26	26	Open cluster close to Antares.
M.13 Herculis	16	40	+36	31	Globular. Just visible to naked eye.
M.92 Herculis	17	16.1	+43	11	Globular. Between Iota and Eta Herculis.
M.6 Scorpii	17	36.8	−32	11	Open cluster; naked-eye.
M.7 Scorpii	17	50.6	−34	48	Very bright open cluster; naked eye.
M.23 Sagittarii	17	54.8	−19	01	Open cluster nearly 50′ in diameter.
H.IV 37 Draconis	17	58.6	+66	38	Bright Planetary.
M.8 Sagittarii	18	01.4	−24	23	Lagoon Nebula. Gaseous. Just visible with naked eye.
NGC 6572 Ophiuchi	18	10.9	+06	50	Bright planetary, between Beta Ophiuchi and Zeta Aquilæ.
M.17 Sagittarii	18	18.8	−16	12	Omega Nebula. Gaseous. Large and bright.
M.11 Scuti	18	49.0	−06	19	Wild Duck. Bright open cluster.
M.57 Lyræ	18	52.6	+32	59	Ring Nebula. Brightest of planetaries.
M.27 Vulpeculæ	19	58.1	+22	37	Dumb-bell Nebula, near Gamma Sagittæ.
H.IV 1 Aquarii	21	02.1	−11	31	Bright planetary near Nu Aquarii.
M.15 Pegasi	21	28.3	+12	01	Bright globular, near Epsilon Pegasi.
M.39 Cygni	21	31.0	+48	17	Open cluster between Deneb and Alpha Lacertæ. Well seen with low powers.

Some Recent Books

Astronomy: The Structure of the Universe, by William J. Kaufmann. Macmillan, 1977. A very clear and comprehensive account of modern astronomy, suitable for the layman and for the serious student.

Exploring the Galaxies, by Simon Mitton. A general account, very clearly written and incorporating the latest results.

Guide to Mars, by Patrick Moore. Lutterworth Press, 1977. An account of Mars as it now appears following the successful Viking missions.

Astronomy: a Dictionary of Space and the Universe, by Iain Nicolson. Arrow Books, 1977. A paperback, the title of which speaks for itself; invaluable as a quick reference book.

Modern Astronomy. Various authors. Sidgwick & Jackson, 1977. Reprints of articles in previous Yearbooks (1962 to 1976), brought up to date where necessary.

Our Contributors

F. R. SPRY is an amateur astronomer who has his observatory at Selsey in Sussex; the main telescope is an 8½ in. reflector. He is concerned mainly with astronomical equipment, and is a regular contributor to the *Yearbook*. He is a Council Member of the British Astronomical Association.

DR R. MADDISON, of Keele University, is also one of our regular contributors. He is in charge of the Astronomy Department at the university, where there is a new observatory equipped with a 24 in. reflector. Though primarily an astrophysicist, he is also deeply involved with problems of the Moon. He is Vice-President of the British Astronomical Association, and is a frequent broadcaster on both television and radio.

J. C. D. MARSH is Senior Lecturer in Astronomy at the Hatfield Polytechnic. He specializes in infra-red astronomy, and has undertaken much original research.

Professor S. MIYAMOTO, of Kwasan Observatory at Kyoto (Japan) has concentrated largely upon lunar and planetary research, and has published many papers upon the subject. He serves on the Lunar and Planetary Commissions of the International Astronomical Union.

DR GARRY E. HUNT, of University College, London, has been deeply involved with the planetary probes, and has been primarily responsible for some of the experiments carried out by them. His main research is in connection with planetary meteorology. He is also well known for his broadcasts on radio and television.

DR JOCELYN BELL BURNELL has worked in radio astronomy (where she was involved with the discovery of pulsars), gamma-ray astronomy, and is now working in X-ray astronomy at the Mullard Space Science Laboratory, University College, London. She helps run the Ariel V X-ray astronomy satellite. She is a Fellow of the Royal Astronomical Society, and until recently has been an editor of *The Observatory* magazine.

DR SIMON MITTON is a Cambridge graduate, and carried out research on radio galaxies until 1971. He is secretary of the Institute of Astronomy at Cambridge, and is the U.K. editor of *Astrophysical Letters.* In addition to his technical writing he has recently published a more 'popular' book, *Exploring the Galaxies.*

HEATHER COUPER is a graduate of the University of Leicester, specializing in research into external galaxies. She is a Council Member of the British Astronomical Association.

IAIN NICOLSON, a regular *Yearbook* contributor, is Lecturer in Astronomy at the Hatfield Polytechnic Observatory. He graduated from the University of St Andrews, and has been concerned largely with infra-red astronomy and interstellar matter. He broadcasts frequently, and has served on the Council of the British Astronomical Association.

Astronomical Societies in Great Britain

The advantages of joining an astronomical society are obvious enough. Full information about national and local Societies was given in the 1966 *Yearbook;* a condensed list, suitably brought up to date, is given below.

Editor's Note. It has been decided to omit subscriptions as they were found to be continually out of date.)

British Astronomical Association
Secretary: J. L. White, Burlington House, Piccadilly, London, W.1.
Meetings: Burlington House, Piccadilly. Last Wed. each month (Oct.-June).

Irish Astronomical Association
Secretary: D. Beesley, The Planetarium, Armagh.
Meetings: Belfast, fortnightly. Armagh, monthly.

Junior Astronomical Society
Secretary: 58 Vaughan Gardens, Ilford, Essex.
Meetings: Alliance Hall, Palmer Street, W.C.1. Last Saturday Jan., April, July, Oct 2.30 p.m.

Aberdeen and District Astronomical Society
Secretary: W. P. Cooper, 14 Abbotshall Gardens, Cults, Aberdeen.
Meetings: Robert-Gordon's Institute of Technology, St Andrew Street, Aberdeen.

Altrincham and District Astronomical Society
Secretary: Colin Henshaw, 10 Delamere Road, Gatley, Cheadle, Cheshire.
Meetings: Park Road Library, Timperley. 1st Friday of each month, 7.30 p.m.

Aylesbury Astronomical Society
Secretary: N. Neale, 9 Elm Close, Butler's Cross, Aylesbury.
Meetings: As arranged.

Birmingham Astronomical Society
Secretary: A. R. J. Foulger, 14 Plants Brook Road, Walmley, Sutton Coldfield.
Meetings: Birmingham and Midland Institute. Monthly.

Border Astronomical Society
Secretary: David Pettit, 14 Shap Grove, Carlisle, Cumbria.
Meetings: Morton Community Centre, Wigton Road, Carlisle. Monthly by arrangement.

Bradford Astronomical Society
Secretary: B. Jones, 28 High House Avenue, Bolton, Bradford, W. Yorks.
Meetings:

Bridgwater Astronomical Society
Secretary: W. L. Buckland, The Bridgwater College, Bridgwater, Somerset.
Meetings: Room 4, Blake Street Centre, Bridgwater College. 3rd Wednesday in each month.

Brighton Astronomical Society
Secretary: Mrs B. C. Smith, Flat 2, 23 Albany Villas, Hove, Sussex, BN3 2RS.
Meetings: Preston Tennis Club, Preston Drive, Brighton. Weekly, Tuesdays.

Bristol Astronomical Society
Secretary: G. H. Woodman, 34 Butterfield Close, Bristol BS10 5AZ.
Meetings: Royal Fort (Rm G44), Bristol University. Last Friday each month, Sept.-May.

Caithness and Dounreay Astronomical Society
Secretary: Miss M. J. A. Clark, Room 31, Ormlie Lodge, Thurso, Scotland.
Meetings: Fortnightly.

Camberley (Surrey) Astronomical Society
Secretary: B. A. Roberts, 45 Ferndale Road, Church Crookham, Aldershot, Hants.
Meetings: (Room B23, Yateley Centre School, School Lane, Yateley, Camberley, Surrey.) 2nd Wednesday each month, 7.45 p.m.

Cambridge Astronomical Society
Secretary: S. R. Whistler, 5 Haggis Gap, Fulbourn.
Meetings: 7 Brooklands Avenue, Cambridge. 2nd Mon. each month Oct.-July.

Cardiff Astronomical Society
Secretary: D. W. S. Powell, 1 Tal-y-Bont Road, Ely, Cardiff.
Meeting Place: Penylan Observatory, Cyncoed Road, Penylan, Cardiff. Alternate Thursdays, 8 p.m.

Chelmsford and District Astronomical Society
Secretary: Miss C. C. Puddick, 6 Walpole Walk, Rayleigh, Essex.
Meetings: 7.45 p.m. Sandon House School, Sandon Near Chelmsford. 2nd and last Monday of Month.

Chelmsley Astronomical Society
Secretary: Miss D. Calvert, 193 Shard End Crescent, Shard End, Birmingham.
Meetings: Chelmsley Wood Library. Last Thursday in month.

Chester Astronomical Society
Secretary: A. Kemp, 37 Alwyn Gardens, Upton, Chester.
Meetings: St Andrews House, Newgate Street, Chester. Monthly.

Chester Society of Natural Science, Literature and Art
Secretary: Paul Braid, 'White Wing', 38 Bryn Avenue, Old Colwyn, Colwyn Bay, Clwyd.
Meetings: Grosvenor Museum, Chester. Fortnightly.

Chesterfield Astronomical Society
Secretary: Mrs R. C. Naylor, Hilltop Cottage, Gallery Lane, Holymoorside. Chesterfield.
Meetings: Barnett Observatory, Newbold. Each Friday.

Clackmannanshire Astronomical Society
Secretary: J. Cluckie, 9 Deer Park, Sauchie, Alloa.
Meetings: St Mary's School, Alloa. Monthly, 3rd Friday, Sept.-May.

Clacton & District Astronomical Association
Secretary: C. L. Haskell, 105 London Road, Clacton-on-Sea, Essex.

Cleethorpes & District Astronomical Society
Secretary: P. H. Rea, 236 Humberston Avenue, Humberston, Grimsby, South Humberside.
Meetings: Beacon Hill Observatory, Cleethorpes. 1st Wednesday each month.

Clwyd Astronomical Society
Secretary: K. J. Payne, 2 Veto Villas, Rhyl Road, Denbigh, Clwyd.
Meetings: Details on request.

Colchester Amateur Astronomers
Secretary: F. Kelly, 'Middleton', Church Road, Elmstead Market, Colchester, Essex.
Meetings: William Loveless Hall, High Street, Wivenhoe. Friday evenings. Fortnightly.

Coventry & Warwicks Astronomical Society
Secretary: 238 Sovereign Road, Earlsdon, Coventry, Warwicks.
Meetings: Coventry Technical College. Fortnightly.

Crawley Astronomical Society
Secretary: G. Cowley, 67 Climpixy Road, Ifield, Crawley, Sussex.
Meetings: Crawley College of Further Education. Monthly Oct.-June.

Crayford Manor House Astronomical Society
Secretary: R. H. Chambers, Manor House Centre, Crayford, Kent.
Meetings: Manor House Centre, Crayford. Monthly during term-time.

Croydon Astronomical Society
Secretary: K. Brackerborough, 342 Lower Addiscombe Road, Croydon.
Meetings: Normanton Park Hotel, 34 Normanton Road, South Croydon. Alternate Fridays, 7.45 p.m.

Dartington Astronomical Society
Secretary: Mrs Iris Allison, 'Wayfaring', Cott Lane, Dartington, Totnes, Devon.
Meetings: Meeting Room, Shinners Bridge Centre, Dartington. 3rd Wed. each month at 8 p.m. Observation all other Wed. evenings (weather permitting) on Foxhole clock tower.

Derby & District Astronomical Society
Secretary: Jane D. Kirk, 7 Cromwell Avenue, Findern, Derby.
Meetings: At home of Secretary. First and third Friday each month, 7.30 p.m.

Dundee Astronomical Society
Secretary: K. Kennedy, 80 Torridon Road, Broughty Ferry, Dundee.
Meetings: Mills Observatory, Dundee. Fortnightly in the winter.

Eastbourne Astronomical Society
Secretary: R. W. Cripps, 10 Framfield Way, Eastbourne.
Meetings: Girl Guide HQ, Hartfield Road, Eastbourne. Last Saturday each month.

East Lancashire Astronomical Society
Secretary: D. Chadwick, 16 Worston Lane, Great Harwood, Blackburn, BB6 7TH.
Meetings: As arranged. Monthly.

Astronomical Society of Edinburgh
Secretary: N. G. Matthew, 126 W. Saville Terrace, Edinburgh 9, Scotland.
Meetings: Calton Hill Observatory, Edinburgh. Monthly.

Ewell Astronomical Society
Secretary: Ron W. Johnson, 19 Elm Way, Ewell, Surrey.
Meetings: Minor Hall, Bourne Hall, Ewell. 1st Friday of each month.

Farnham Astronomical Society
Secretary: John Fannon, 10 Willow Way, Hale, Farnham, Surrey.
Meetings: Adult Education Centre, 32 South Street, Farnham. 2nd Monday each month, 7.45 p.m.

Fellowship of Junior Astronomers, Edinburgh
Secretary: Miss Edith McLean, 58 Ogilvie Terrace, Edinburgh 11, Scotland.
Meetings: Calton Hill Observatory, Edinburgh. 3rd Fri. each month, Sept-June.

Furness Astronomical Society
Secretary: R. Alldridge, 56 Hartington Street, Barrow-in-Furness, Cumbria.
Meetings: Barrow Library. 1st Saturday in month, 2 p.m.

Fylde Astronomical Society
Secretary: 28 Belvedere Road, Thornton, Lancs.
Meetings: Stanley Hall, Rossendale Ave. South. 1st Wed. each month.

Astronomical Society of Glasgow
Secretary: H. Palmer, 8 Kirkoswald Road, Newlands, Glasgow.
Meetings: University of Strathclyde, George Street, Glasgow. 3rd Thurs. each month, Sept.-April.

Great Yarmouth Astronomical Society
Secretary: M. Poxon, 10 Tyrrels Road, Great Yarmouth, Norfolk.
Meetings: Public Library. Alternate Fridays.

Guildford Astronomical Society
Secretary: Mrs D. E. Clapson, 12 Durham Close, Guildford.
Meetings: Corona Restaurant, High Street, Guildford. 1st Tue. each month, 7.45 p.m.

Gwynedd Astronomical Society
Secretary: E. Parry, 2 Rhes Groes, Sling, Bangor, Gwynedd.
Meetings: Physics Lecture Room, Bangor University. 1st Thurs. each month, 7.30 p.m.

Astronomical Society of Haringey
Secretary: W. T. Baker, 58 Stirling Road, Wood Green, London, N.22.
Meetings: 673 Lordship Lane, Wood Green, London, N.22. 3rd Thurs. each month, 7.30 p.m.

The Hampshire Astronomical Group
Secretary: S. W. Hackman, 52 Denbigh Drive, Fareham, Hampshire.
Meetings: The Group Observatory.

Harlow Astronomical Group
Secretary: R. Marsh, 9 Charters Cross, Harlow, Essex.
Meetings: 62 Priory Court, Harlow. Tuesdays, fortnightly, 7.30 p.m.

Herschel Society
Secretary: C/o Taylor Public Library, Slough.

Hull and East Riding Astronomical Society
Secretary: J. I. Booth, 3 Lyngarth Av., Cottingham, North Humberside.
Meetings: College of Higher Education, Queen's Gardens, Hull. Third Friday each month, Oct.-April.

Isle of Wight Astronomical Society
Secretary: J. W. Feakins, 1 Hilltop Cottages, High Street, Freshwater, Isle of Wight.
Meetings: Unitarian Church Hall, Newport, Isle of Wight. Monthly.

Lancaster University Astronomical Society
Secretary: G. Day, Lunar and Planetary Unit, University of Lancaster.
Meetings:

Leeds Astronomical Society
Secretary: M. D. Taylor, 17 Cross Lane, Wakefield, West Yorks.
Meetings: Leeds City Museum/Library. 2nd Wed. each month.

Leicester Astronomical Society
Secretary: Mrs L. Withey, 26 Falmouth Road, Evington, Leicester.
Meetings: Leicester Museum and Art Gallery. Monthly.

Lincoln Astronomical Society
Secretary: Robert D. Christy, 41 Meadow Lake Crescent, Birchwood, Lincoln.
Meetings: The Lecture Hall, off Westcliffe Street, Lincoln. First Tues. each month.

Liverpool Astronomical Society
Secretary: D. Bradburne, Simms Cross School House, Mitton Road, Widnes.
Meetings: City Museum, Liverpool. Monthly.

Livingston Astronomical Society
Secretary: 50 Dawson Avenue, Howden, Livingston, West Lothian.
Meetings: Almond Room, Howden House, Howden. Sundays, 7.30 p.m.

Loughton Astronomical Society
Secretary: S. Smith, 6 Baldock Road, Theydon Bois, Epping, Essex.
Meetings: Loughton Hall, Rectory Lane, Loughton, Essex. Thurs., 8 p.m.

Luton Astronomical Society
Secretary: S. J. Anderson, 20 Bloomfield Avenue, Luton.
Meetings: Last Friday each month.

Lytham St. Annes Astronomical Association
Secretary: K. J. Porter, 141 Blackpool Road, Ansdell, Lytham St. Annes, Lancs.
Meetings: College of Further Education, Clifton Drive S., Lytham St. Annes. 2nd Wed. monthly Oct.-June.

Maidenhead Astronomical Society
Secretary: Mr C. Wise, 592 Bath Road, Taplow, Maidenhead, Berks.
Meetings: Maidenhead Grammar School. Every 2nd Thursday. Sept.-June.

Maidenhead Astronomy Group
Secretary: S. A. H. Roper, 129 Fane Way, Maidenhead, Berkshire.
Meetings: Maidenhead Grammar School. Once every 3 weeks.

Manchester Astronomical Society
Secretary: J. H. Davidson, Godlee Observatory, U.M.I.S.T., Sackville Street, Manchester 1.
Meetings: At the Observatory, Thursdays, 7.30-9 p.m.

Mansfield & District Astronomical Society
Secretary: G. W. Shepherd, 14 Bonnington Crescent, Sherwood Estate, Nottingham.
Meetings: Monks Precision Engineering Co., Mansfield Road, Sutton-in-Ashfield. Last Monday of each calendar month.

Mid-Sussex Astronomical Society
Secretary: Dr L. K. Brundle, 63 Pasture Hill Road, Haywards Heath, Sussex.
Meetings: Haywards Heath School, Harlands Road. Wednesdays, 7.30 p.m.

Milton Keynes Astronomical Society
Secretary: Paul D. Keen, 26 Betty's Close, Newton Longville, Milton Keynes, MK17 0AN.
Meetings: Alternate Tuesdays.

Newcastle-on-Tyne Astronomical Society
Secretary: G. E. Manville, 30 Kew Gardens, Whitley Bay, Northumberland.
Meetings: Botany Lecture Theatre, Newcastle University. Monthly, Sept.-April.

Newtonian Observatory Astronomical Society
Secretary: Miss P. E. Randle, 62 Northcott Road, Worthing, Sussex.
Meetings: Adult Education Centre, Union Place, Worthing. 1st Wed. each month except Aug. 7.30. p.m.

North Devon Astronomical Society
Secretary: R. W. Rose, Ararat, 18 The Shields, Ilfracombe, North Devon.
Meetings: Details to be announced later.

North Dorset Astronomical Society
Secretary: J. E. M. Coward, The Pharmacy, Stalbridge, Dorset.
Meetings: Charterhay, Stourton, Caundle, Dorset. 2nd Wed. each month.

North Staffordshire Astronomical Society
Secretary: E. S. Hewitt, 24 Weldon Avenue, Weston Coyney, Stoke-on-Trent.

Meetings: 1st Wed. of each month at Cartwright House, Broad Street, Hanley. No sub. fixed yet.

North Western Association of Variable Star Observers
Secretary: Jeremy Bullivant, 2 Beaminster Road, Heaton Mersey, Stockport, Cheshire SK4 3HT.
Meetings: Four annually.

North Wilts/South Glos Astronomical Group
Secretary: Simon D. Barnes, 'Kelston', Gloucester Road, Malmesbury, Wilts.
Meetings: To be announced.

Norwich Astronomical Society
Secretary: Rev. Cyril D. Blount, The Manse, Back Lane, Wymondham, Norwich.
Meetings: Norwich Observatory, Colney Lane, Cringleford, Norwich. Every Tues. and Sat. Public meetings 3rd Sat. at Spinney Community Centre.

Nottingham Astronomical Society
Secretary: C. Swift, 18 Naseby Close, Heathfield, Nottingham.
Meetings: Monthly.

Orwell Astronomical Society (Ipswich)
Secretary: M. Hadden, 33 Crofton Road, Ipswich, Suffolk.
Meetings: Orwell Park School, Nacton, Ipswich. Weekly.

Oxshott Astronomical Group
Secretary: E. H. Noon, Norman Cottage, Pond Piece, Sheath Lane, Oxshott, Surrey.
Meetings: Oxshott Village Centre. 1st Wed. each month Sept.-May.

Paisley Astronomical Society
Secretary: Mrs J. Holms, 14 Cheviot Avenue, Barrhead, Glasgow.
Meetings: Coats Observatory, 49 Oakshaw Street, Paisley. Monthly.

Peterborough Astronomical Society
Secretary: E. Pitchford, 24 Cissbury Ring, Werrington, Peterborough.
Meetings: Peterborough Technical College. 2nd Tues., 3rd Thur. each month.

Phoenix Astronomical Society
Secretary: B. Jones, 38 Myers Avenue, Bolton, Bradford 2, Yorks.
Meetings: Phoenix Park Sports Club, off Dick Lane, Thornbury, Bradford 3.

Plymouth Astronomical Society
Secretary: G. S. Pearce, 1 Valletort Cotts, Millbridge, Plymouth.
Meetings: Y.W.C.A., Lockyer Street, Plymouth. Monthly.

Portsmouth Astronomical Society
Secretary: G. B. Bryant, 81 Ringwood Road, Southsea.
Meetings: Monday. Fortnightly.

Preston & District Astronomical Society
Secretary: C. Lynch, 35 Bispham Road, Carleton, Poulton-le-Fylde, Lancs.
Meetings: Chamber of Commerce, 49a Fishergate, Preston. 3rd Mon. each month. Sept.-May.

Rayleigh Centre Amateur Astronomical Society
Secretary: Bernard R. Soley, 136 The Chase, Rayleigh, Essex.
Meetings: Fitzwimarc School, Hockley Road, Rayleigh. Every Wed., 8 p.m.

Reading Astronomical Society
Secretary: J. Wrigley, 30 Amherst Road, Reading.
Meetings: Anderson Baptist Church Hall, Reading. Monthly.

Salford Astronomical Society
Secretary: J. A. Handford, 45 Burnside Avenue, Salford 6, Lancs.
Meetings: The Observatory, Chaseley Road, Salford.

Salisbury Plain Astronomical Society
Secretary: R. J. D. Nias, St George's Cottage, Orcheston, Salisbury, Wilts.
Meetings: St George's Rectory, Orcheston. Quarterly.

Scarborough & District Astronomical Society
Secretary: M. D. Wilson, 19 Ryefield Close, Eastfield, Scarborough, N. Yorks YO11 3DN.
Meetings: Osgodby Community Centre, Fortnightly, Fridays.

Sheffield Astronomical Society
Secretary: Mrs Nora Betts, 35 Upper Albert Road, Sheffield.
Meetings: City Museum, Weston Bank. Third Friday each month, Sept.-May inclusive.

Slough Astronomical Society
Secretary: E. Shilton, The Elms, Odds Farm, Green Common Lane, Wooburn Common, High Wycombe, Bucks.
Meetings: Monthly.

Solent Amateur Astronomers
Secretary: K. W. Arbour, 14 Orchard Avenue, Bishopstoke, Eastleigh, Hants.
Meetings: Room 33, Library Block, Southampton University. 3rd Thur. each month, 7.30 p.m.

Southampton Astronomical Society
Secretary: J. G. Thompson, 4 Heathfield, Dibden Purlieu, Southampton.
Meetings: 2nd Thur. each month Unigate Conference Room, Southampton; 4th Thur. each month Room 33, University of Southampton.

South Downs Astronomical Society
Secretary: Mrs Buss, 32 Birdham Close, Stroud Green, Bognor Regis.
Meetings: Last Friday in each month.

South-East Essex Astronomical Society
Secretary: P. A. Laycock, 42 First Avenue, Westcliff-on-Sea, Essex SS0 8HR.
Meetings: Lecture Theatre, Central Library, Victoria Avenue, Southend-on-Sea. Generally 1st Thurs. in month, Sept.-May.

South-East Kent Astronomical Society
Secretary: P. Andrew, 30 Reach Close, St Margaret's Bay, nr Dover.
Meetings: Monthly.

South Lincolnshire Astronomical & Geophysical Society
Secretary: F. F. Bermingham, 19 Field Close, Gosberton, Spalding, Lincs.
Meetings: South Holland Centre, Spalding. 1st Monday each month, 7.30 p.m.

Southport Astronomical Society
Secretary: Howard Bloch, 4 Warren Green, Formby, Merseyside.
Meetings: Saturday evenings, monthly as arranged.

South Shields Astronomical Society
Secretary: H. Haysham, Marine and Technical College, St George's Ave., South Shields, Co. Durham.
Meetings: Marine and Technical College. Each Thurs., 7.30 p.m.

South West Herts Astronomical Society
Secretary: G. J. B. Phillips, 32 Riverford Close, Harpenden, Herts.
Meetings: Royal Masonic School for Girls, Rickmansworth. Last Fri. each month, Sept.-May.

Stoke-on-Trent Astronomical Society
Secretary: M. Pace, Sundale, Dunnocksfold Road, Alsager, Stoke.
Meetings: Cartwright House, Broad Street, Hanley. Monthly.

Swansea Astronomical Society
Secretary: C. Morris, 14 Bath Villas, Morriston, Swansea SA6 7AN.
Meetings: As arranged.

Thames Valley Astronomical Group
Secretary: K. J. Pallet, 82a Tennyson Street, South Lambeth, London, SW8 3TH.
Meetings: Irregular.

Thanet Amateur Astronomical Society
Secretary: P. F. Jordan, 85 Crescent Road, Ramsgate.
Meetings: Hilderstone House, Broadstairs Kent. Monthly.

Torbay Astronomical Society
Secretary: Miss A. Longman, 4 Heath Rise, Brixham, Devon.
Meetings: Quay Tor Hotel, Scarborough Road, Torquay. Monthly.

Waltham Forest & District Junior Astronomy Club
Secretary: B. Crawford, 24 Fulbourne Road, Walthamstow, London E.17.
Meetings: 24 Fulbourne Road, Walthamstow, London E.17. Fortnightly (Mondays).

Warrington Astronomical Society
Secretary: B. P. Rees, 2 Dale Avenue, Appleton, Warrington.
Meetings: Central Library, Museum Street, Warrington, Lancs. Monthly, Sept.-May.

Warwickshire Astronomical Society
Secretary: R. D. Wood, 20 Humber Road, Coventry, Warwickshire.
Meetings: 20 Humber Road, Coventry. Each Tuesday.

Webb Society
Secretary: E. Moore, 7 Elvendon Road, Palmers Green, London, N.13.
Meetings: As arranged.

Wessex Astronomical Group
Secretary: Mrs J. Broadbank, 624 Ringwood Road, Parkstone, Poole, Dorset.
Meetings: Science Block B, Lower Annex, Poole Technical College.

West of London Astronomical Society
Secretary: R. A. Hedley, 96 Warden Avenue, Rayners Lane, Harrow, Middlesex, HA2 9LW.
Meetings: Monthly, alternately at Hillingdon and North Harrow. Second Monday of the month, except August.

West Yorkshire Astronomical Society
Secretary: J. A. Roberts, 76 Katrina Grove, Purston, Pontefract, Yorks, WF7 5LW.
Meetings: The Barn, 4 The Butts, Back Northgate, Pontefract. Every Tues., 7 p.m.

Wolverhampton Astronomical Society
Secretary: M. Astley, Garwick, 8 Holme Mill, Fordhouses, Wolverhampton.
Meetings: Polytechnic, Wulfruna Street, Wolverhampton. Alternate Mon., Sept.-April.

Wyvern Astronomical Society
Secretary: A. F. Edwards, 2 Howcroft, Churchdown, Gloucester.
Meetings: Clubhouse, Churcham. Last Friday of each month except Aug.

York Astronomical Society
Secretary: Mrs J. Acton, 1 Low Catton Road, Stamford Bridge, York.
Meetings: York Railway Institute. Fortnightly, Fridays.

Zenith Astronomical Society
Secretary: A. Harvey, 10 Meadow Close, Reedby, nr Burnley.
Meetings: 54 Cromwell Street, Burnley. 1st Wednesday in each month.

It is possible that this list of local societies may not be quite complete. If any have been omitted, or any details need to be updated, the secretaries concerned are invited to write to the Editor (c/o Messrs Sidgwick & Jackson (Publishers), Ltd, 1 Tavistock Chambers, Bloomsbury Way, London WC1), so that the relevant notes may be included in the 1979 *Yearbook*.

The Editor

Patrick Moore, O.B.E., was born in 1923 in Pinner, Middlesex. In the Second World War he served as an officer in the Royal Air Force, flying as a navigator in Bomber Command. He spent many years at East Grinstead, Sussex; was Director of the Armagh Planetarium (Northern Ireland), 1965-68. Following that he moved to Selsey and now has his own private observatory, with a 15-inch reflector as the main telescope. His main astronomical interests are the Moon and the Planets. He is a member of the International Astronomical Union, and a Fellow of the Royal Astronomical Society. He has recently been presented with the Jackson-Gwilt Medal by the R.A.S. His O.B.E. was awarded in 1967. He is currently Vice-President of the British Astronomical Association.

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